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This technical report focuses on Military Satellite Control Technologies and their application to the Air Force Satellite Control Network (AFSCN). This report is a compilation of articles that provide an overview of the AFSCN and the Advanced Technology Program, and discusses relevant technical issues and developments applicable to the AFSCN. Among the topics covered are articles on Future Technology projections; Future AFSCN topologies; Modeling of the AFSCN; Wide Area Communications Technology evolution; Automating AFSCN Resource Scheduling; Health & Status monitoring at Remote Tracking Stations; Software metrics and tools for measuring AFSCN software performance; Human-Computer Interface Working Group; Trusted Systems Workshop; and the University Technical Interaction Program.

In addition, Key Technology Area points of contact are listed in the report

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CONTACT: A TECHNICAL REPORT ON MILITARY SATELLITE CONTROL TECHNOLOGY

Prepared 9 July 1993

Prepared by:
Space and Missile Systems Center
Satellite Control and Data Handling System Program Office

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Chief, Advanced Technology Branch

FOR THE COMMANDER

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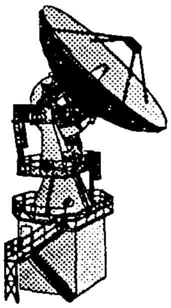

Contact

An Air Force Technical Report on Military Satellite Control Technology September 1993

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Topologies and Technologies for the Future AFSCN

Automating AFSCN Resource Scheduling

Remote Tracking Station Health and Status Monitoring

Software Metrics and Tools

Modeling the AFSCN

The Human-Computer Interface Working Group

Trusted Systems Workshop

Wide Area Network Communications Technologies Evolution

University Technical Interaction Program

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The AFSCN Advanced Technology Program

An Overview

Captain James E. Takach, USAF

BACKGROUND

The Air Force Satellite Control Network (AFSCN) is a network of systems whose mission, according to the "AFSCN Definition Document" dated 23 February 1993, is to:

> *". . . provide Telemetry, Tracking, and Commanding (TT&C), communications, mission data distribution and data processing support to operational Department of Defense space systems, RDT&E (Research, Development, Test and Evaluation) space systems, and other assigned programs."*

The AFSCN is operated by Air Force Space Command, has nine worldwide fixed remote tracking stations, and has mission control nodes at Onizuka AFB, CA and Falcon AFB, CO. The Air Force Space and Missile Systems Center's Satellite Control and Data Handling System Program Office (SMC/CW) at Los Angeles AFB, CA, is the primary development agent for the AFSCN.

In addition to substantial data processing and communications, the AFSCN performs a multitude of functions, including:

- Telemetry receipt, relay, and analysis
- Satellite command
- Satellite tracking and orbit determination
- Mission data distribution
- Resource scheduling.

SMC/CW has found it increasingly difficult to be both responsive to user needs and to keep pace with escalating technological advancements. As a result, the level of technology in many AFSCN systems historically lags that available in the commercial world.

In order to address this situation the Program Director, Satellite Control and Data Handling Program Office, sponsored the creation of an Advanced Technology Program (ATP) for the AFSCN and charged the Architecture and Technology Division (CWIA) with execution of the Program.

CWIA is tasked with advancing the state of the art of military satellite command and control by developing cost-effective AFSCN architecture options for the next 2 through 25 year time frame. Options that most effectively satisfy documented and projected user requirements will be proposed to the AFSCN developers. A major goal of the ATP is that of developing and implementing a process to ensure that emerging and forecasted technological advances are considered in developing the options.

The Advanced Technology Program is an integral part of the Technology Master Process (TMP) defined by HQ AFMC (reference "Guide to the Technology Master Process," 30 Oct 92). Specificallv, the members involved with AFSCN ATP participate in Technical Planning Integrated Product Teams (TPIPTs). This includes assisting with the development of TPIPT System-technology Roadmaps, supporting Technology Development Planning, supporting Technology Transition Planning, providing inputs to Technology Investment Recommendation Reports, and assisting with development of Strategic Technology Investment Plans as required by AFMC/ST.

To most effectively support the TMP, CWIA has established objectives and processes for the AFSCN ATP. The five objectives of the ATP are to:

- Assess and forecast future technologies
- Locate, evaluate, demonstrate, and schedule the transition of selected technologies into the AFSCN
- Provide an effective architecture and technology information service
- Establish and maintain a resource base of people, organizations, and capabilities involved with advanced technology
- Develop and coordinate technology strategies for R&D funding advocacy.

ADVANCED TECHNOLOGY PROGRAM PROCESS

The following summarizes CWIA's systematic procedure for addressing the technology infusion challenge. The CWIA Government/industry ATP team approach consists of the following steps:

1. Identify Promising Technologies: To do this, CWIA has defined AFSCN Key Technology Areas (KTAs) in which to concentrate the research and infusion effort. Currently there are six KTAs:

- Communications
- Computing Systems
- Human-Computer Interfaces (HCI)
- Modeling and Analytical Techniques

- Tracking and Orbit Determination
- Support Environment.

In each KTA, researchers identify emerging and possible future technologies that offer promise of improving performance and/or reducing cost in the AFSCN over the next 25 years. These technologies are then subdivided into "Topic Areas" that group the technologies for forecasting purposes. Examples of topic areas for each KTA are presented later in this article.

2. Identify Metrics: For each "Topic Area," researchers identify AFSCN-relevant performance, cost, and risk metrics useful for assessing the potential for infusion of these technologies into the AFSCN. These metrics are intended to be consistent with those being identified by other AFSCN bodies, such as the AFSCN Network Performance Team.

3. Develop Forecasts: Researchers develop forecasts for:

- The maturation of the technologies in that area
- The likely availabilities for AFSCN use of products that incorporate those technologies.

These forecasts include values for the metrics identified, and show the anticipated improvements in the values over time.

4. Capture and Make Available the Above Information in a Database: To preserve the above information and to facilitate its use in technology infusion, CWIA is developing an Advanced Technology Database (ATDB). KTA researchers have already documented, and included in the initial version of the ATDB, substantial information on relevant technological developments.

5. Perform Analyses and Develop Infusion Roadmaps: This is the process that ties together the advanced technology and planning efforts. It is a multi-step procedure, requiring a coordinated effort across many KTAs, in which the researchers:

- Analyze future AFSCN requirements and employ an integrated technology infusion methodology to identify system and subsystem-level solutions that are enabled by complementary technological advances in several areas
- Assess technological risk of the solutions as entities
- Employ modeling and other analytical techniques to evaluate and compare the cost and performance of proposed solutions against each other, as well as against the projected network cost and performance were no such solutions implemented.
- Where appropriate, perform feasibility demonstrations for recommended solutions, both for individual technologies and for aggregates
- Recommend solutions and develop roadmaps linking the availability of enabling technologies to solutions of future requirements.

ATP PROCESS IMPLEMENTATION

To facilitate the above work, CWIA is developing a Technology Analysis Guide (TAG). The TAG will provide ATP team members with a cohesive tool and approach for performing the challenging tasks of technology analysis and infusion opportunity identification.

Complementary to the TAG is the building of a Technology Resource Network (TRN), which is a network of people and organizations with advanced technology interests common to those of CWIA. The TRN consists of AFSCN users and developers, government lab personnel, universities, contractors, and other government agencies.

CWIA disseminates ATP information to the TRN on a continual basis. Means by which this is accomplished include:

- Meeting with members of the TRN and briefing them on our activities
- Making the ATDB available to the TRN
- Distributing to the TRN this CWIA Technical Report, which includes articles written by ATP participants
- Preparing and distributing proceedings of CWIA-sponsored symposia and workshops
- Submitting papers to conferences and journals
- Publishing periodic summary reports.

Since the TRN includes AFSCN operators and developers, distribution of ATP information also helps serve the objective of increasing the AFSCN community's awareness of technological opportunities.

CWIA also aggressively pursues externally oriented activities that promote the development of information and technologies beneficial to the AFSCN. One such effort is identifying and providing advocacy for R&D activities that promote promising technologies. Forms of this advocacy include:

- Participating in AF TPIPTs
- Distributing information on CWIA objectives, programs, and activities, including KTA Strategy Plans

- Reviewing and providing input to Technology Area Plans (TAPs) of Government Laboratories
- Participating in annual meetings, such as AF Lab Spring Reviews
- Supporting development of dual use technologies.

Additional outreach activities include:

- Suggesting thesis topics to AFIT and other university students, and supporting the development of those theses
- Sponsoring AFSCN-specific symposia and workshops (e.g., Trusted Systems, Artificial Intelligence/Expert Systems, EHF/SHF for TT&C)
- Supporting Small Business Ventures, including the Small Business Innovative Research Program (SBIR).

THE SIX AFSCN KEY TECHNOLOGY AREAS

As indicated earlier, six AFSCN-oriented Key Technology Areas provide the focus through which the above processes are accomplished. The objectives of the AFSCN KTAs are captured in Strategy Plans for each Area. Objectives common to each KTA are to provide enabling technology options for more reliable, more survivable, more capable, and lower cost AFSCN near-term (present) and far-term (25 year) architectures. By necessity, the KTA Strategy process is tied closely to Air Force budget (POM) planning.

Some of the Topic Areas for the six KTAs include:

Communications
Satellite earth terminal transmitter and receiver "front ends" at S-band, SHF, and EHF; processing repeaters; optical fiber transmission technology; microwave transmission technology; waveforms and coding for BW and SNR efficiency in SATCOM; space-to-space links; cellular technology; data network design and topology; multiplexer and switch technology; robust transmission; network management.

Computing Systems
Parallel processing (SIMD, computing meshes, instruction overlap), devices (ruggedized components, MMICs for RF, MCMs), microelectronics and photonics (GaAs devices, InP devices, high-temp superconductors, vertical and 3-D constructs, low-voltage devices, nanoeletronics, molecular electronics, optical devices and switching, hologram applications, hybrid electronic/photonic architectures), software (software re-use, software fault tree analysis, Petri-net analysis).

Human-Computer Interfaces
Decision support aids, virtual reality, speech recognition, multi-media, portable systems, adaptive user interfaces, GUIs, artificial intelligence, groupware, natural language interfaces, speech synthesis.

Modeling and Analytical Techniques
Hardware/software environments, object-oriented programming, knowledge representation, operations research, scheduling theory, mathematical programming, AI/expert systems, fuzzy logic, neural networks/self-learning engines, dynamic systems (cellular automata), computational ecology.

Tracking and Orbit Determination
Tracking technology (radiometric, optical, and autonomous tracking techniques), orbit determination/estimation technology, and modeling technologies.

Support Environment
Uninterruptible power supplies, security (physical and electronic), status sensing devises, policy/procedure/methodology improvements, alternative energy sources, construction materials.

CONCLUSION

In a time of decreasing budgets and increasing demands, it is imperative that the AFSCN's Improvement and Modernization efforts take advantage of the most cost-effective measures. The Advanced Technology Program is providing a unique and significant contribution toward that end.

Captain James E. Takach, USAF, managed the SMC/CW Advanced Technology Program from August 1992 to June 1993.. He obtained a Bachelor's Degree in Electrical Engineering from Rensselaer Polytechnic Institute in 1987, and he is currently working towards a Master's Degree in Electrical Engineering at UCLA with emphasis in Communications. He spent his first few years at SMC managing AFSCN communications integration and system testing and supporting the integration of the Automated Remote Tracking Station program into the Network.

Future Technology Projections: Methods and Faults

An Example for Making Projections:
Data Storage Density

Lin Sten, C&DP/Paramax

Linear extrapolation of data storage density 10 years in the future based on historical data is used as an example of how to make technology projections. Also illustrated is a method of estimating the amount of error in this particular projection. This paper gives examples of errors in past projections of other technologies and general comments about the limitations of making projections. It describes how even error-free projection may contain implicit faults.

INTRODUCTION

This paper is about making projections for future technologies. Data storage density was chosen as an example technology for illustrating projections, because it is readily quantifiable and has an abundance of historical data. Thus, it serves as an example technology for which projections can be made when conditions for projection seem excellent. It also brings to light projection errors that may still arise.

DATA STORAGE DENSITY PROJECTIONS

For cartridge tape, a 10-year extrapolation is given in Figure 1 (Richards 1991). Data from Table 1 is the basis for Figure 1. The vertical axis is scaled logarithmically and presents storage density in bits per square inch on the tape. The horizontal axis shows the year in which the given tape was (or will be) put on the market.

The figure gives past and present data, and shows a least squares linear best fit for the data cartridge data, which are represented by solid squares. The line through the data cartridge squares is extended into the future; this is a simple linear extrapolation of the logarithm of density versus time. This extrapolation can be viewed as a 10-year projection of storage density to the year 2000. This projection shows a one order-of-magnitude (a factor of 10) increase in storage density between the years 1990 and 2000.

In a non-linear projection, the figure shows almost two orders of magnitude (10**2) increase in storage density for Gbyte data cartridges between the years 1992 and 2000.

Linear extrapolation is a very popular method of making projections, both because it is easy, and because it is often hard to justify doing anything more complex. Usually the best justification for a linear extrapolation is the historical data. If past data fall on a straight line, the best assumption is that it will continue to do so in the future; although this is often the best assumption, it is not necessarily a good assumption.

The introduction of a completely new technology or product sometimes occurs suddenly, as shown with the Gbyte data cartridge, and it can violate the assumptions on which an earlier extrapolation was based. The quality of the assumption often can be judged only when the future becomes the present.

ERRORS IN MAKING PROJECTIONS ABOUT DATA STORAGE DENSITY PROJECTIONS

Errors will exist in projections about the future of any technology. But there are ways to estimate such errors. An example of how to estimate the error in the above type of linear extrapolation about data storage density is given below.

Imagine that in 1980 an attempt was made to project cartridge storage density that would be available in 1990. A reasonable method for having made such a projection could have been based on Figure 1 and Table 1, as follows. Make a simple linear extrapolation up through 1990, based on the semi-log straight line curve, for (solid square) data prior to 1980, in Figure 1. As Figure 1 shows, the result would have been fairly accurate: the linear extrapolation (based on logarithms of the densities) using the values in the Table for 1973.0 and 1977.0 gives 3.63 Mbits per square inch for 1989.8 while 1.79 Mbits per square inch was actually achieved. In this case there would have been a factor-of-2 error in the 10-year projection.

Statistical confidence in a single datum is zero; thus, it is understood that the factor-2 error in a 10-year projection has no general applicability, even when restricted to storage density on tape. To obtain an error result with general applicability, better statistics (i.e., more than one datum) must be used. Two data points, that is, two errors, can be used.

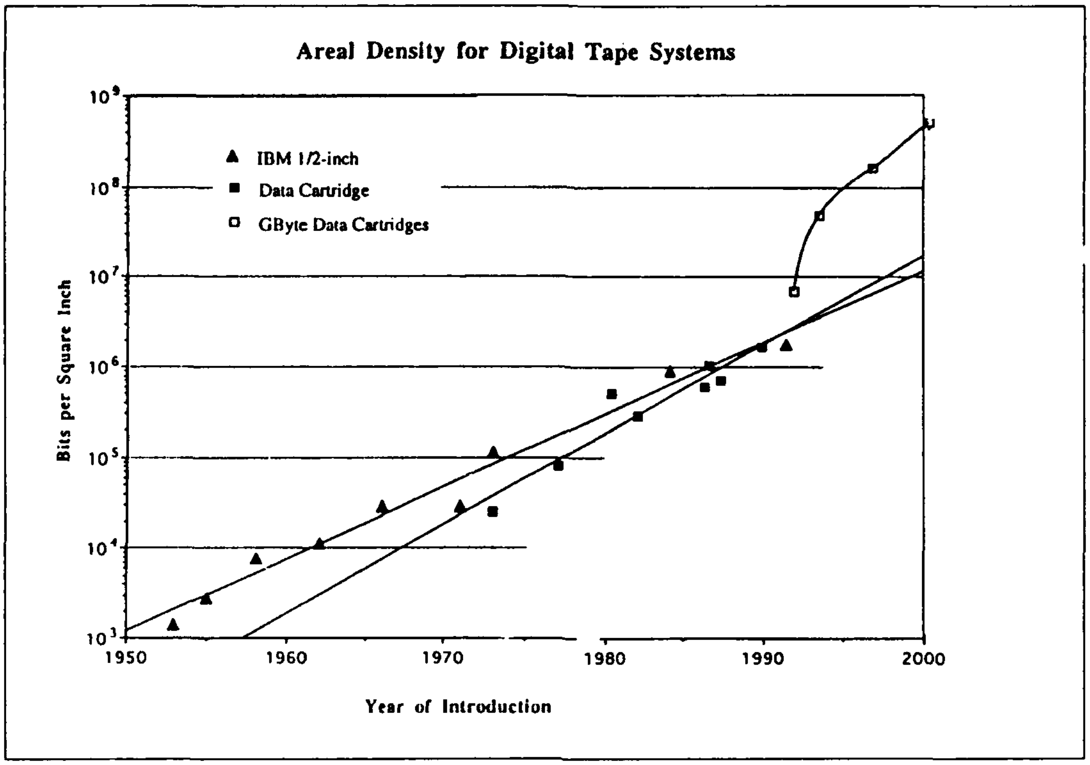

Figure 1: Areal Density for Digital Tape Systems

For a second, independent, *assessment of potential errors* in making data storage density projections, Figure 1 (and Table 1) can be examined from another point of view. Look at the semi-log straight line curve based on data up through 1990. Compare the straight line extrapolation for data cartridges (solid squares) in the year 2000 with the projection given for Gbyte data cartridges (open squares) in the year 2000: The first of these is 20 Mbits per square inch, and the second is 538 Mbits per square inch.

An error in making a 10-year projection is identified by the fact that these two projections differ by more than an order of magnitude (538/20 = 27). That these two projections apply to different products and that both projections are correct for their respective products is not important to researchers who want to know generally about projection errors in storage density on tape. This single error gives an initial estimate of the errors that might lie in present projections of future storage densities, a factor of 27 every 10 years.

As determined from the above projections, a factor-2 error applies to the period 1980-1990, and a factor-27 error to the period 1990-2000. Averaging these two equates to averaging their base 10 logarithms (since it is a base 10 semi-log straight line that is seen): This means averaging exponents 0.30 and 1.43, to obtain the average exponent 0.86. Thus, the 10-year projection error is 10**(0.86), i.e., a factor-7 error for a 10-year projection.

This estimated error, a factor of 7 for every 10 years, can generally be applied with more confidence than either of the other two errors. Nonetheless, since only two data were used, the statistical confidence in the correctness of this error is still quite low.

Just as a comparison was made above between two different tape products to assess projection errors, it would be equally valid to make the comparison between tape and any other future technology which might replace tape.

PAST ERRORS IN MAKING OTHER KINDS OF PROJECTIONS

Brody (1991) and Drexler (1990) offer some interesting examples of how technological projections can go awry. Brody states: "Theoretically, it's been possible for the past 25 years for computers to eliminate photographic film...Continuing chemical refinements have kept silver-halide in the center of the picture despite a strong challenge from electronic imaging media." Other examples are:

System#	Year	Tracks	TPI	BPI	Density (bits/in2)	Length (feet)	Raw Cap. (bytes)	Formatted Cap. (bytes)	Speed (in/sec)	Xfer Rate (char/sec)
IBM 726	1953	7	13.92	100	3.39E+03	2400	2.38E+06	2.52E+06	75	7500
IBM 727	1955	7	13.92	200	2.78E+03	2400	5.76E+06	5.04E+06	75	15000
IBM 729-III	1958	7	13.92	556	7.74E+03	2400	1.60E+07	1.40E+07	112.5	62550
IBM 729-VI	1962	7	13.92	800	1.11E+04	2400	2.30E+07	2.02E+07	112.5	90000
IBM 2401-6	1966	9	17.92	1600	2.87E+04	2400	4.61E+07	4.03E+07	112.5	180000
IBM 3420-7	1971	9	17.92	1600	2.87E+04	2400	4.61E+07	4.03E+07	200	320000
IBM 3420-8	1973	9	17.92	6250	1.12E+05	2400	1.80E+08	1.53E+08	200	1250000
3M DCD-3	1973.0	4	17.2	1600	2.75E+04	300	2.88E+06	2.38E+06	30	4.95E+03
?	1977.0	4	17.2	5120	8.79E+04	300	9.22E+06	7.60E+06	30	1.58E+04
3MHCD-75	1980.3	16	68.7	8000	5.49E+05	600	1.15E+08	6.68E+07	90	5.22E+04
QIC 24	1982.0	9	38.6	8000	3.09E+055	450	4.86E+07	4.01E+07	60	4.95E+04
IBM 3480	1984	18	35.92	25000	8.98E+05	525	3.25E+08	2.21E+08	78.8	3940000
QIC 120	1986.2	15	64.4	10000	6.44E+05	600	1.35E+08	1.15E+08	120	1.28E+05
QIC 150	1987.2	18	77.3	10000	7.73E+05	600	1.62E+08	1.34E+08	120	1.24E+05
3M HCD-134	1987.4	32	137.3	8000	1.10E+06	600	2.30E+08	1.38E+08	120	7.20E+04
QIC 320	1989.8	26	111.6	16000	1.79E+06	600	3.74E+08	3.09E+08	120	1.98E+05
QIC 525	1989.8	26	111.6	16000	1.79E+06	1020	6.36E+08	5.25E+08	120	1.98E+05 (sustained)
G-1	1991.3	30	133.3	51667	6.89E+06	750	1.74E+09	1.34E+09	120	5.97E+05
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M4/G2	Q1 1992	144	747.1	67666	5.06E+07	925	1.35E+10	1.05E+10	120	1.58E+06
G3	1996	216	1121.1	150000	1.68E+08	925	4.50E+10	3.51E+10	120	3.51E+06
G4	2000	432	2242.2	240000	5.38E+08	925	1.44E+11	1.12E+11	120	5.62E+06

Table 1: Large Data Cartridge Trends

- Improvements in optical lithography are expected to carry feature dimension on silicon chips down to a quarter of a micron; whereas, in the 1970s it was expected that this limit would be one micron. So far such improvements in silicon chips have kept a theoretical competitor, the Josephson junction, at bay.
- Likewise, the heralded gallium-arsenide chip revolution has still not occurred, again due to continuing advances in (the old) silicon technology.

Drexler gives many quantitative and qualitative examples that serve as much as a warning about our point of view as they do about what quantitative numbers we project. He quotes from an entry in the diary of 1800s British Astronomer Royal, Sir George Airy. "...asked my opinion on the utility of Babbage's calculating machine...I replied...that it was utterly worthless." (Drexler, p. 68) Even in hindsight, this opinion proves valid, for Babbage's machine was utterly worthless given its use and the technology for its improvement at that time. In hindsight it was simply a machine of great potential which it may be inferred Sir Airy failed to recognize. In 1956 another Astronomer Royal went awry: He stated that, "Space travel is utter bilge." (Drexler, p. 84) Yuri Gagarin traveled in space in 1961.

AN IMPLICIT FAULT IN ERROR-FREE PROJECTION TO THE YEAR 2015

As technology evolves, the usefulness of various measures changes. For example, the amount of coal an engine burned per hour was important once, but such engines are no longer relevant. There is no guarantee that data storage density will have the same meaning in the future as it does today. In the same way that many related issues, such as access time and cost, will change in importance as the AFSCN evolves, so too will new issues arise.

For example, in twenty years the storage density measure addressed here may be irrelevant. At that time, possibly only associative memory data storage density will be meaningful.

No matter how perfect a projection method is for any chosen measure, what really will happen becomes rather uncertain as many evolving and new technologies are synthesized in the future. This encourages a broad point of view, and familiarity across a spectrum of technologies, for each individual in the Key Technology Area group.

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Topologies and Technologies for the Future AFSCN

Making Space for the AFSCN of the Future

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The Air Force Satellite Control Network (AFSCN) performs the functions of space vehicle command and control, telemetry reception and processing, orbit determination, and other related activities for DoD spacecraft. The current topology of the Network, a dual star configuration, has evolved over the years in response to increasing demands and advances in technology. This paper explores other topologies for the future such as a three-star topology using relay satellites, a multiple-ring topology with crosslinks, and mixed topologies. Also discussed are the key components and technologies that must be developed and tested before such new topologies can be implemented: standardized crosslink transmission packages; on-board processing for data transmission, error control, and up/down and crosslink switching; efficient EHF up/downlink packages; and AI/expert systems for spacecraft autonomy and spacecraft control.

1. INTRODUCTION

The Air Force Satellite Control Network (AFSCN) is a network of systems forming a major portion of the DoD satellite control capability and has evolved considerably since its inception 30 years ago. It has successfully performed its function of checkout, operation, and maintenance of all DoD spacecraft, and has also provided launch support for DoD, NASA, and other space programs. In this time period, the AFSCN has gone through continuous growth, modification, and refurbishment to adjust to the ever-growing number of DoD spacecraft and the increasing complexity of keeping them healthy in orbit.

The AFSCN recently completed modernization of its command and control systems under Data Systems Modernization and is presently completing a major range automation upgrade under the Automated Remote Tracking Stations (ARTS) program. These improvements notwithstanding, it is not too early to look in the more distant future and study how emerging technologies may allow not only further improvements, but also significant and improved reconfigurations of the AFSCN we know today.

This paper discusses, first, the topology of the present network and its perceived shortcomings; second, a number of alternative topologies that are considered candidates for the future; and third, specific technology advancements that could make a difference in the selection of the winning candidate.

2. PRESENT AFSCN TOPOLOGY

The AFSCN currently consists of nine worldwide, geographically dispersed Remote Tracking Stations (RTSs) and two CONUS-located control nodes. Figure 1 shows the current AFSCN topology supporting a representative population of satellites in low-, medium-, and high-altitude orbits. The squares (labeled C) represent the two control nodes from which all spacecraft are controlled. These are presently located in Colorado Springs, Colorado, and in Sunnyvale, California.

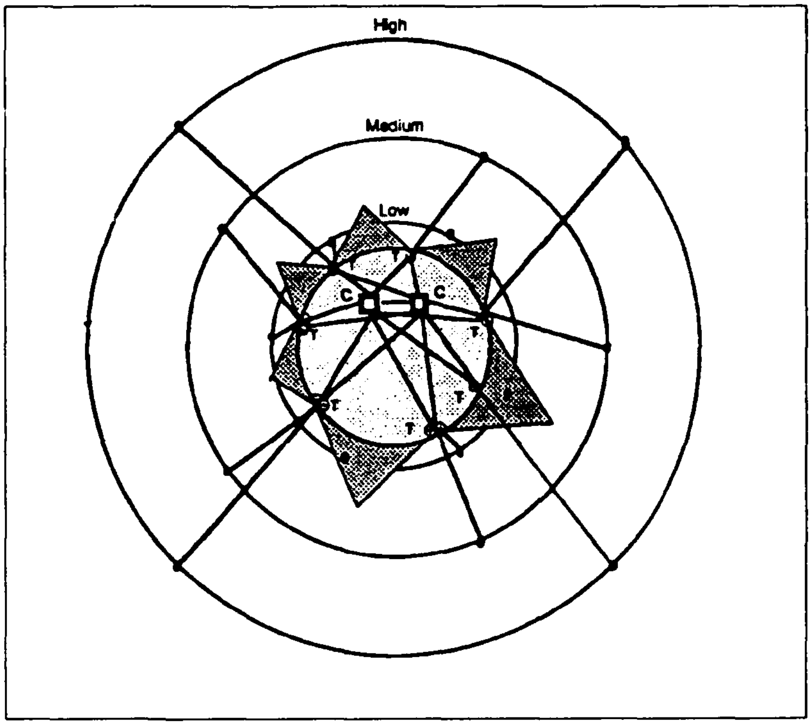

Figure 1: The Double Star Topology of the Current AFSCN

The Remote Tracking Stations (labeled T) are connected to the two control nodes in a dual-star configuration. The RTSs are the Telemetry, Tracking and Command (TT&C) assets that provide the interface between the AFSCN and the mission vehicle. The nodes control the vehicles through this interface. The connections between the Ts and Cs are shown in the figure as straight lines and are composed of land lines, line-of-sight (LOS) radio links, and satellite links using DoD and commercial communication satellites. Some tracking stations are single sided in that they have one antenna for the AFSCN/mission vehicle interface. Other stations are dual sided, and one has three sides. All stations have separate antenna systems for node-to-station communications, although TT&C antennas can be configured for data relay.

The geosynchronous spacecraft (in the high orbits) are visible to the same tracking station for extended periods, whereas other spacecraft must be handed-off between tracking stations with a frequency that depends on, among other things, their altitude. Some spacecraft require continuous RTS support, while others require only occasional contact.

Figure 1 illustrates two deficiencies of this network configuration. First, a spacecraft may be temporarily located in one of the "holes" (shaded triangles) of the coverage area resulting from visibility limits. However, this problem exists only for Low Earth Orbit (LEO) vehicles. Also, RTS capacity may be exceeded if the number of spacecraft requiring contact is greater than the number of antennas available at the location. In either case, a desired contact may have to be delayed or an ongoing transmission interrupted.

Other disadvantages also accrue with this configuration. Most are related to the fact that the stations must be widely dispersed. Consequently, most RTSs are located overseas and on foreign territory. This incurs large expenses for: (1) foreign real estate, (2) a worldwide communication network, (3) overseas personnel, and (4) global logistics support. In addition, political circumstances within the host countries are always uncertain.

Change to the present AFSCN configuration should remedy at least one, if not all, of these disadvantages. Candidates for such a change are discussed in the following paragraphs.

3. EXPANSION OF CURRENT TOPOLOGY

In the past, requirements for servicing additional spacecraft and for increased coverage area (i.e., fewer holes) have been met by adding new ground locations and antennas. A continuation of this approach is the first logical candidate configuration to consider.

Since only Low Earth Orbit (LEO) vehicles suffer from coverage gaps, additional ground locations could be specialized for low orbits. Such stations would function with smaller antenna diameters, less RF power, and less powerful receivers. Accordingly, they would require less prime power, smaller plots of real estate, and a less conspicuous profile. Also, these small stations could be unmanned and remotely controlled, requiring only occasional maintenance visits. Additionally, mobile TT&C assets can be deployed to provide coverage of the gaps. Such assets could also be relocated to provide support during anomaly resolutions, launches, etc.

Every additional station increases the total coverage area and decreases the chance of overloading existing locations. Smaller size and remote control of each LEO station reduces its relative cost. Total network cost, however, would increase with each additional station, and the overseas/foreign-soil problems would be exacerbated with each additional site. Note, however, that this approach does not require much in the way of new technology and thus can provide a back-up solution if the hoped-for technology advancements required for the following candidates do not materialize.

4. THREE-STAR CONFIGURATION WITH RELAY SATELLITES

Figure 2 shows a topology that has been under discussion within the Air Force for many years.[1,2,3,4] In this configuration, the remote stations are replaced by geosynchronous relay satellites (labeled R), similar to the NASA Tracking Data Relay Satellite System (TDRSS).

The control complexes connect through two up/downlinks, with the two Rs in their view. The third R is connected via redundant relay crosslinks. Additional redundancy may be accommodated by a third R-to-R crosslink between the upper Rs. Each mission satellite connects to its closest R via a mission crosslink. The design consequences are:

- There are only two ground antennas (excluding redundancy).
- The data rate on the remaining up/downlinks is greatly increased (the total up/downlink requirements are unchanged).
- The relays must carry a large number of crosslinks and a sophisticated switch to handle ever-changing traffic loads and handovers between mission satellites, the relays, and the two ground stations.
- Fault detection and fault isolation become difficult.
- Resource control becomes more difficult.
- Orbit determination becomes more difficult, since the tracking stations themselves are moving.

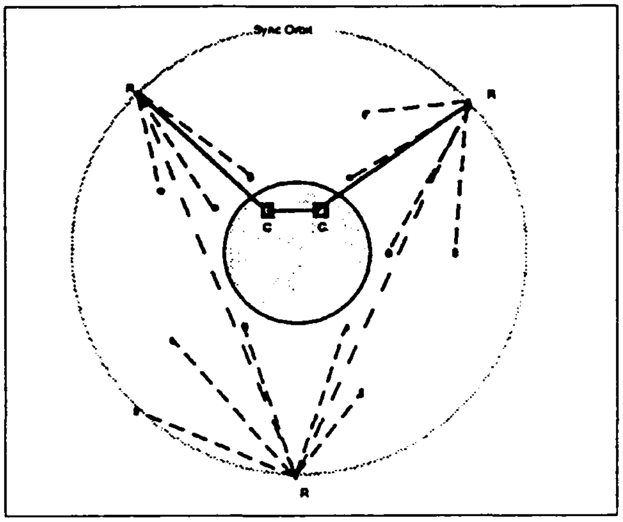

Figure 2: Network Using Common Relay Satelites

The future DoD satellite population requiring AFSCN support may easily surpass a hundred, especially with the recent emphasis on small, special-purpose spacecraft. The number of crosslinks that would be required on the relay satellites seems overwhelming; however, the situation is not as bleak as it seems.

As with the present network, not all of these spacecraft would need simultaneous support. Although some spacecraft require continuous, dedicated, high data rate connections to the ground, others need only periodic updates (e.g., navigation satellites), and others require only a weekly contact (e.g., certain communication satellites). Thus, the total number of crosslinks may not be much higher than the present number of ground antennas. In addition, some of the crosslinks require only a low data rate. However, mission crosslinks must switch rapidly from one mission spacecraft to another, with at least the same speed at which present ground antennas switch.

High initial costs have prevented AFSCN topology to incorporate relay satellites. Periodic reevaluation is in order as technology and priorities progress.

5. RING TOPOLOGY WITH CROSSLINKS

Figure 3 shows a ring topology proposed with the once-expected massive deployment of SDI spacecraft. Here, each ring of mission satellites in the same orbital plane provides its own connectivity through crosslinks. One spacecraft of the ring, the "token holder", connects the whole ring via an up/downlink to a control node. The token holder changes as the spacecraft move along their orbit. Compared with the previous topology of three relay satellites, the following changes are evident

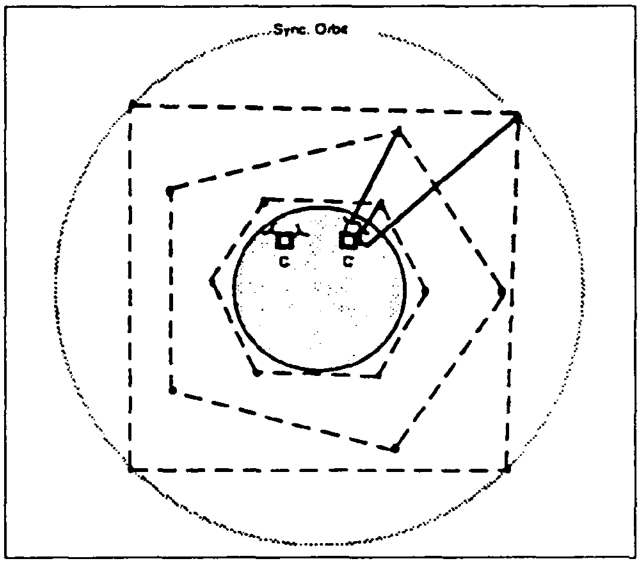

Figure 3: Network Using Dedicated Crosslinks

- Separate relay satellites are not needed, since all crosslinks are carried by the mission satellites.
- The number of ground antennas is equal to the number of satellite rings.
- The mission crosslinks are less demanding than for relay satellites:
  - For low fliers, the crosslink distances are smaller, allowing less RF (or laser) power and thus lower weight.
  - There is no switching of crosslinks.
  - Data rates are reduced compared to the rate between the relay satellites of the three-star topology.
- The issues with resource control, fault detection/isolation, and orbit determination remain for this topology.

This approach can be extended for satellite constellations with multiple-orbit planes by providing crosslinks between the orbital planes. This reduces the number of ground antennas. One can extend this concept by providing crosslinks between different constellations. However, the topologies and switchover processes become unwieldy.

6. MIXED TOPOLOGIES

It is doubtful that any single topology will shape the AFSCN of the future. More likely, the AFSCN of the twenty-first century will combine several of the topologies described above.

Although the number of large remote stations may be substantially reduced, one expects a proliferation of small, possibly transportable stations, to accommodate the large number of small, low-altitude spacecraft that are currently under development.

Large constellations will likely have their own intra-orbit or intra-constellation crosslinks. This will permit continuous monitoring and control of an entire constellation with only a single up/downlink.

For those programs having only one or a few spacecraft, a relay system may be the best solution. In the presence of the other topologies, such a relay system could be less ambitious than the one described in Section Four, since it would serve fewer mission spacecraft. It might be possible to put the relay package on host spacecraft, such as a future Defense Satellite Communication System (DSCS) spacecraft.

The exact AFSCN configuration of the future depends largely on the success of certain key technology developments.

7. SUPPORTING TECHNOLOGIES

Several key components will enable the configurations described above to become reality. Although these components are currently unavailable, ongoing development and prototype testing should be completed within a decade. The following components are required:

- A standardized small, lightweight crosslink transmission package
- Intelligent on-board processing for data transmission, error control, and up/down and crosslink switching and network management
- A lightweight, efficient EHF up/downlink package
- AI and special subsystems for spacecraft autonomy.

7.1 Crosslink Transmission Package

Crosslink communications may mitigate the bottlenecks and costs attending Remote Tracking Stations and terrestrial communications relays. These links are characterized by large distances and lossless, broadband propagation media. Typically, these links have been implemented in the 60-GHz band[5,6] corresponding to the water vapor absorption band to avoid terrestrial interference. Optical carriers are potentially applicable when the technology matures. Large bandwidths are available at millimeter wave and optical frequencies, but the transatmospheric bottleneck must still be accommodated.

Crosslinks are typically SNR-constrained, since aperture and transmit power are severely constrained in these applications. Large apertures are heavy, and at the crosslink transmission wavelength, high-gain antennas incur severe spatial signal acquisition and tracking problems. The large crosslink bandpass permits a signal design tradeoff in which bandwidth may be expended in exchange for SNR efficiency. Large forward error-correcting coding (FEC) overhead may be employed to minimize the crosslink transmitter power and antenna size. For this overhead to not impact the downlinks, the crosslink receiver is required to demodulate and error-correct on board — technology whose time has not yet come.

The standardized small, lightweight crosslink package should easily adapt to any spacecraft singly, in pairs, or in larger numbers (on the order of ten). It should be self-sufficient with a processor that rapidly accomplishes search, acquisition, and tracking upon receiving the ephemerides of the two satellites to be linked. The package also should determine the precise range and range rate between the two spacecraft.

7.2 On-board Processing

On-board processing has taken on the stigma of "...the technology of the future, it always has been, it always will be." NASA, over the last decade, and in the context of the Advanced Communication Technology Satellite (ACTS) program, has explored several on-board processor technologies and subsystems. These studies have focused on TDMA processing repeaters; earlier studies have focused on packet transmission processors. The main effort has been in the satellite-switched TDMA (SSTDMA) technology, in which signals are switched and routed from uplinks to designated downlinks. The switching is performed on a microsecond scale, and a large multiple-access multisubscriber environment is supported. Such a system may be applied to the telemetry data collection and command relay satellite processor that is simultaneously supporting several mission satellites.

The communications processor illustrated in Figure 4 may also handle the up/downlink gateway function and perform modulation, coding and their inverse functions. Data buffering, time tagging, and multiplexing are additional processes to be considered for this system. The component technology is currently capable of performing these complex functions at very high processing rates and with low weight and low power devices.

7.3 EHF Up/Downlink Package

Either as a standalone command and telemetry, or as a dual-function communications package supporting crosslink and up/downlink transmission, a transponder, processing repeater and/or transmitter/receiver must transit the atmospheric path to/from the tracking station or the earth station terrestrial gateway. If future missions required the relay of very high data rates in the Gbps range, bandwidth-efficient transmission methods must be considered. Also, EIRP and G/T affects demand, at the same time, highly SNR-efficient transmission technology. These requirements act in opposition to one another, and careful system study is required for selecting compromise solutions.

In general, highly bandwidth-efficient waveforms are comprised of complex amplitude and phase-modulated transmission symbols that exhibit considerable envelope variation. To minimize transmitter distortion and signal detection degradation, "linearized" transmitters are indicated for use. Current TWTAs exhibit maximum conversion efficiency (RF output power divided by DC power consump-

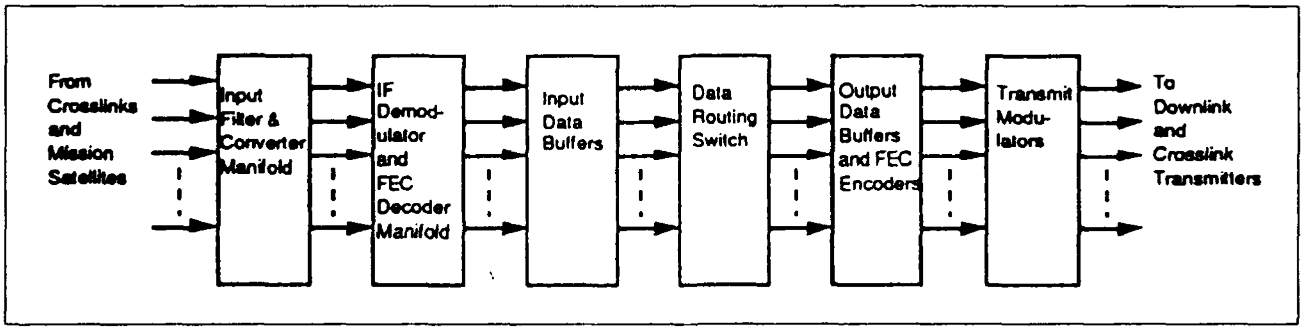

Figure 4: Switching-Processing Repeater and Gateway

tion) when driven close to the region of saturation. Unfortunately, distortion is also highest in this region, and significant backoff in RF output power does not result in a corresponding reduction in DC power consumption, and highly inefficient operation results. Considerable work is in process on TWTAs that can operate close to saturated output power and maintain high linearity properties. Significant progress at EHF, however, is yet to be reported.

The lightweight EHF up/downlink subsystem should be a standard package that can be installed on all spacecraft to support the AFSCN functions. It may also be required to interface with small transportable ground stations.

7.4 AI AND SPECIAL SUBSYSTEMS

The relay spacecraft, as well as many of the mission spacecraft in any of the described configurations, should reduce maintenance and required intervention from the AFSCN. As such, artificial intelligence systems, coupled with new sensors, can automate attitude and orbit control, navigation, switch control, anomaly resolution, traffic routing, multiple-beam antenna control, and payload control functions now performed by the AFSCN or the user organization.

Most likely, many of the AI systems will be imbedded in the software and firmware of the various subsystems they help to control. They will reduce up/downlink and crosslink traffic and reduce the required manpower for control.

8. SUMMARY AND CONCLUSIONS

Efforts are ongoing in all the above technology areas. However, as experience shows, technology progress is difficult to predict. On the other hand, technology breakthroughs can happen unexpectedly. The AFSCN topology will likely go through an evolutionary process, incorporating new configurations as pertinent technologies become available, and reducing or dropping older configurations as they become obsolete or when the equipment wears out. The AFSCN is expected to evolve in concert with the introduction of new spacecraft programs and/or block changes of existing ones.

To stay abreast of progress in the applicable technology areas, the Satellite Control and Data Handling System Program Office of the AF Space and Missiles Systems Center has instituted the Advanced Technology Program. The goal of this program is to monitor ongoing R&D projects in DoD and industry in the United States and abroad, to evaluate their utility for future AFSCN applications, and to make the community aware of AFSCN technology interests and requirements. This paper is an effort in this direction.

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Automating AFSCN Resource Scheduling

Resource Scheduling: What Is It? Why Should We Want to Automate It? Can We Automate It?

Randall Chesnut, C&DP/Scitor Corporation

This article discusses the complexities involved in developing the daily schedules for allocating AFSCN tracking station antennas and other communication resources. The scheduling tools in use today are briefly described, and scheduling load projections for the future are provided. Options for increasing the level of automation in the scheduling process are presented, and the importance and advantages of providing such automation aids is discussed. Lastly, past efforts at automating scheduling processes outside of the AFSCN are discussed.

BACKGROUND

The Air Force Satellite Control Network (AFSCN) is responsible for providing a number of support functions for DoD satellites. These functions include satellite tracking, receipt of telemetry and payload data from satellites, and transmission of commands to satellites. The AFSCN has nine fixed-location tracking stations located around the world, a mission control node located at Onizuka AFB in California, and another mission control node located at Falcon AFB in Colorado.

During a typical satellite support, a tracking station tracks the satellite and receives telemetry and possibly payload data. Telemetry and payload data are relayed to a Mission Control Complex (MCC) at one of the control nodes. The MCC can also send to the tracking station commands to be transmitted to the satellite. This whole process is referred to as a contact support.

In addition to MCC equipment and communication equipment for linking an MCC with a tracking station, each contact support requires a certain set of equipment at the tracking station. Such tracking station equipment includes, for example, antennas of various sizes, transmitters, receivers, and modulators/demodulators of various types. There is significant variation in the equipment complement from one tracking station to another, and certain contact supports can only be accomplished by certain tracking stations. Some tracking stations can perform only one contact support at a time, while others have multiple sets of equipment and can perform two or three supports concurrently. At one of these tracking stations, each set of equipment for performing a contact support is referred to as a 'side', and such tracking stations are referred to as 'multi-sided'.
Since the nine tracking stations must be shared by all of the AFSCN's satellite users, contact supports must be carefully scheduled to avoid conflicts and satisfy user requirements as fully as possible. This article deals with this scheduling process and the possible future automation of it.

1. OVERVIEW OF AFSCN RESOURCE SCHEDULING

The AFSCN resource scheduling function is performed in two Range Control Complexes (RCCs). One RCC is located at Onizuka AFB, and the other is located at Falcon AFB. Scheduled activities fall into two broad categories: 'flight' tasks and 'non-flight' tasks. A flight task involves the tracking of a satellite and the transfer of telemetry and commands between a Mission Control Complex (MCC) and the satellite via communication links and a tracking station. Non-flight tasks are tasks which do not directly involve a satellite contact support. Examples of non-flight tasks are equipment maintenance and upgrade activities.

Scheduling is currently performed for 3 different time periods: an upcoming 7-day period, an upcoming 24-hour period, and periods during the execution of a 24-hour schedule. Figure 1 provides a simplified illustration of the scheduling function interfaces. The scheduling process starts with users from the MCCs providing requests for contact supports to the schedulers for an upcoming 7-day period. These requests are provided in a form referred to as a Program Action Plan (PAP). The schedulers are also provided with schedule requests for maintenance activities on the equipment used for the contact supports. Similarly, information regarding equipment which is currently out of service and cannot be used for contact supports is also provided to the schedulers.

Another important input to the scheduling process is satellite visibility data. For an upcoming specific stretch of time, this data specifies each time period during which a satellite will be visible from each tracking station. These are the time windows during which contact supports can be scheduled. Satellites in true geosynchronous orbit will be constantly visible to some subset of tracking stations. Visibility periods for other satellites, however, range from ten minutes or less for low altitude satellites to several hours for medium altitude satellites. This data is provided on Satellite Acquisition Tapes (SATs).

The schedulers also use a database of relatively static information referred to as Environment data. Some of the important items in this database include:

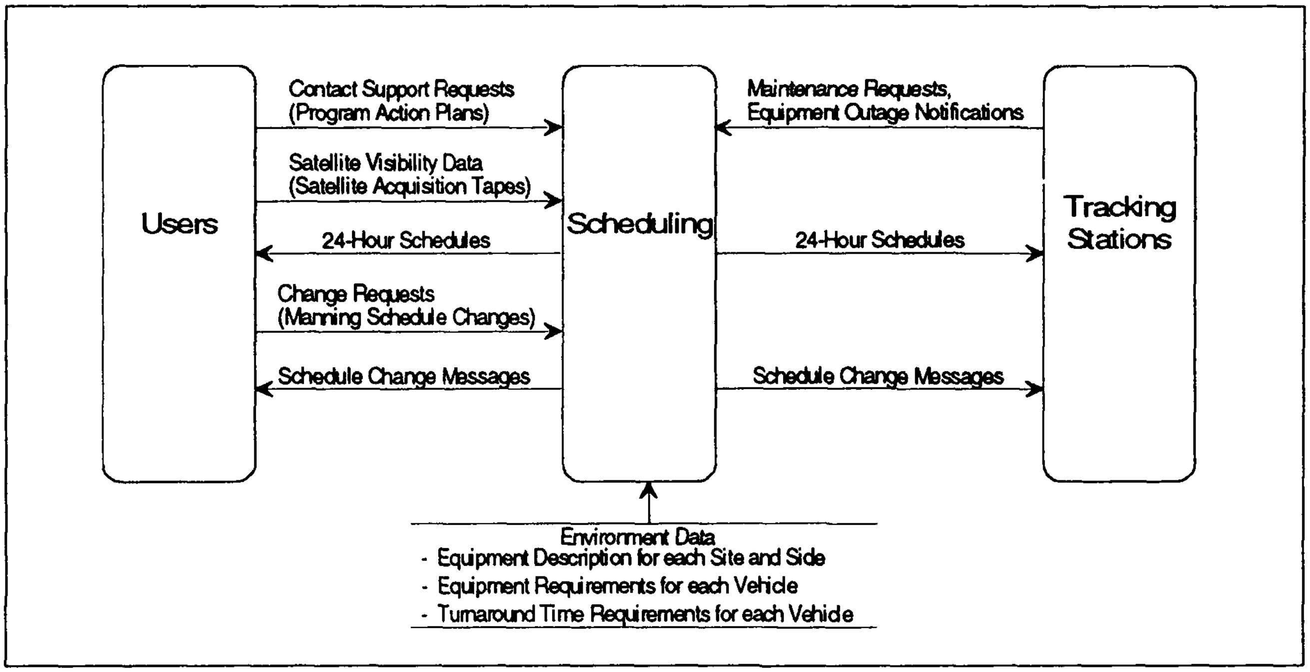

Figure 1: Simplified Resource Scheduling Interfaces

- the set of equipment items available at each side of each tracking station
- an indication of which equipment can be switched between different sides of a tracking station
- for each satellite vehicle, the set of equipment nominally required for a support for that vehicle
- for each satellite vehicle, the nominal required turnaround time for that vehicle. (Turnaround time is a time period immediately prior to a contact support. The tracking station, communication equipment, and MCC are configured for the support during this period. This is also known as 'Prepass time'.)
- for each combination of a vehicle and a tracking station side that can support that vehicle, a list of any deviations required for this tracking station side from the vehicle's nominal TAT or equipment set.

Between the time the users provide the 7-day scheduling request inputs and the time at which production of a 24-hour schedule for an imminent 24-hour period must be constructed, users can and do submit changes to their original requests. These change requests are referred to as Manning Schedule Changes. The number of these change requests is so great that the schedulers do not attempt to create final schedules prior to producing the 24-hour schedule.

After a 24-hour schedule is produced, it is sent to the MCCs and the tracking stations. Schedule changes are still made, however, after the schedule has been published and is being executed. These real-time changes are necessitated by unexpected changes in support requirements (e.g., due to a launch slip), unexpected equipment failures, and errors discovered in the schedule. The users and tracking stations are advised of such changes to the schedule by means of Schedule Change Messages (SCMs).

1.1 SCHEDULING CONSTRAINTS

The process of actually scheduling tasks is made difficult by the complex set of time and resource constraints which determine the allowable times for scheduling a task. The tracking station antennas and their associated communication equipment constitute the most basic resource constraint. No more than one flight task can use a given antenna and its associated equipment during the same time period.

Another type of resource constraint arises from the fact that multi-sided tracking stations have equipment that can be switched between the different sides of the site. The various sides of a site typically have a large number of equipment item types in common. When an item fails on one side, the same type of item from a different side can often be switched in to perform the failed item's function. In a situation such as this, concurrent tasks can still be scheduled at each side, but scheduling concurrent tasks which use the equipment item being shared must be prevented.

Resources other than those at the tracking stations themselves are referred to a range resources. Limitations of these resources impose additional constraints. A maximum number of concurrent users is associated with each range resource. The number of concurrently scheduled tasks which use such a resource must not exceed that resource's maximum user limit. An example of such a resource is the pool of range controller consoles. During the turnaround time for a task, a range controller is responsible for configuring and testing the resources which will be used for the task. Since the number of range controllers is limited, the number of tasks that can be scheduled with concurrent turnaround times is likewise limited.

The fact that scheduling requests can specify relative preferences for resources is another factor which must be taken into consideration. For example, excessive noise may be present in the telemetry received from a vehicle by a particular tracking station. A support request for that vehicle will include that tracking station in its list of acceptable sites (since noisy telemetry may be better than none at all), but the request will also specify a preference for support from the other acceptable tracking stations.

There are at least as many time constraints that must be considered when scheduling a task as there are resource constraints. One of the most basic time constraints is the one mentioned above dealing with satellite visibilities, i.e., a support can only be scheduled at a given tracking station when the corresponding vehicle is visible from that station. A number of additional time constraints can also be specified, such as the following:

- preferred start time, earliest possible start time, and latest possible start time
- preferred duration for a task and minimum usable duration for the task
- preferred turnaround time for a task and minimum allowed turnaround time for the task
- requirement or a preference for a task to be scheduled (or not to be scheduled) concurrently with another specified task
- specification that a task be scheduled within a specified maximum and minimum time from the time another specified task gets scheduled.

Schedulers must also take into account potential Radio Frequency Interference (RFI) conflicts when producing a schedule. An RFI conflict occurs when two or more satellites using the same radio frequency are in conjunction from the perspective of a tracking station providing support. (Conjunction is considered to occur when two or more satellites come within a visibility cone angle of 3 to 5 degrees at a tracking station.) In order to avoid (or remove) RFI conflicts in the schedule, schedulers are provided with a listing of conjunctions between satellites which use common radio frequencies.

Another factor to be considered is varying priorities associated with support requests. Priorities are not fixed for task types, vehicles, or even families of vehicles. Instead, priorities change in a dynamic and subjective manner based on a combination of factors such as current mission objectives associated with a given support, the length of time since a vehicle's last support, the age of the vehicle, the performance record of vehicles in the same family, whether the vehicle is about to enter a solar eclipse period, etc.

Since a large number of real-time changes to a schedule are inevitably required, another consideration in producing the schedule is how well suited the schedule is to accommodating such changes. When making a change to a schedule which has already been published, it is desirable for the change to impact as few of the existing scheduled tasks as possible. Consequently, strategies such as spreading tasks roughly evenly across the tracking stations and avoiding back-to-back task scheduling to the degree possible may result in schedules that are more amenable to modification.

In summary, the process of scheduling is one of selecting times and resources for tasks such that the above described constraints are met and as many of the specified preferences are also satisfied. It is often the case that not all of the requirements specified by the support requests can be satisfied. These situations are referred to as 'hard conflicts'. In such cases the schedulers must negotiate with the users to decide whose support request will not be satisfied.

1.2 CURRENT SCHEDULING TOOLS

A system called ASTRO (Automated Scheduling Tools for Range Operations) is currently the central component used for resource scheduling. A prototype ASTRO system was replaced by a full-scale system in both RCCs during 1992. By the end of that year, all scheduling operations had transitioned from paper-based scheduling chart methodologies (which had been in use since the early 1960s) to the ASTRO system. ASTRO supports interactive entry and modification of schedule tasks via relatively advanced user interface technology such as 2k x 2k color raster graphics displays, voice recognition, and speech synthesis. ASTRO has eliminated the need to keep a paper-based schedule and a computer-based schedule synchronized, and this has already significantly reduced the labor required for the scheduling activity. ASTRO also performs a large number of tests to ensure that scheduled tasks do not violate constraints associated with corresponding support requests. The process of choosing the time slot and resources that will be used for a task is still, however, a manual one. This is true for both the creation of the 24-hour schedule as well as for the development of real-time schedule modifications.

2. MOTIVATIONS FOR IMPROVED AUTOMATION IN AFSCN RESOURCE SCHEDULING

There are a number of reasons for increasing the level of automation in AFSCN resource scheduling. The most obvious benefit of such automation is a reduction in labor required by the scheduling process. Each RCC is currently staffed on a 3 shifts per day, 7 days per week basis. Several people per shift are devoted to scheduling. Even though ASTRO has already reduced labor requirements, many hours every day are spent entering schedule requests and request modifications, manually shuffling tasks to produce a conflict-free 24-hour schedule, and manually making real-time schedule modifications.

Another significant time expense which is sometimes overlooked is that of training new schedulers. Due to the many intricacies of the current manual scheduling process, experienced schedulers must spend significant effort in the training of a new person for this job. The job is difficult to master and some people are not able to reach a fully productive level even after several months of on-the-job training.

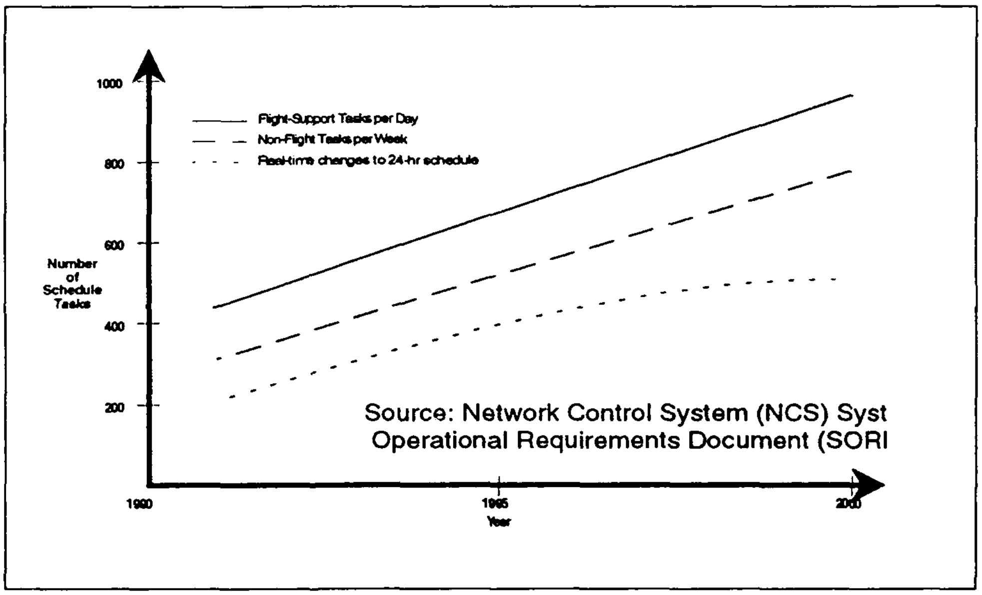

Figure 2: AFSCN Resource Scheduling Load Projections

The time required for scheduling will obviously increase as the number of tasks to be scheduled increases. The number of schedule requests for a given time period has been increasing throughout the history of the AFSCN. This trend is expected to continue. Figure 2 provides an estimation of how these requirements will continue to increase over the next several years.

Another benefit of additional scheduling automation is better utilization of AFSCN resources and better satisfaction of AFSCN user requirements. Complex scheduling problems can arise in which it is beyond the ability of a human to find a solution within a reasonable length of time. Currently, in such situations a user may be forced to give up a support period that an automated system may have been able to schedule. The frequency of occurrence of such situations using the current manual system will increase as the number of tasks to be scheduled increases in the future.

3. CANDIDATE AREAS FOR RESOURCE SCHEDULING AUTOMATION

As the above discussions suggest, prime candidates for additional resource scheduling automation are the processes of producing the 24-hour schedule and making real-time revisions to existing schedules. While it is probably not practical to make these processes completely automatic at any time in the reasonably near future, interactive tools can be developed to significantly reduce the number of labor hours they require. Such tools would shift human effort away from the details of developing conflict-free schedules and toward the process of adjusting task priorities and selecting between multiple candidate schedules automatically produced by the system. The system would still allow the scheduler to manually position and modify tasks, much as ASTRO currently does, in order to meet special requirements. The scheduler could also indicate that such tasks be 'locked' to the specified time and resources, then the automatic process could be run to attempt to shuffle other tasks into conflict-free schedule configurations. When the process cannot find a conflict-free schedule, it could present multiple candidate schedules with different conflict configurations to the scheduler. The scheduler would then be responsible for selecting one of these schedules with hard conflicts and negotiating with the users to resolve such conflicts.

Other areas that can benefit from more common technology center on scheduling system data input and output processes. Schedule requests (PAPs) are currently provided to the schedulers via either magnetic tape or paper. The Operations Planning (OPPLN) software that the MCCs use to produce these tapes can be awkward to use and does not fully meet the needs of all users. This is clearly another area for potential improvement. Effective computer-based methods for preparing the PAPs can be provided to eliminate the practice of providing PAPs to the schedulers in paper form. A logical additional step would be to transmit the PAPs electronically to the scheduling system, eliminating the need for the transfer of any form of hand-carried media.

The technology used for schedule dissemination also merits attention. Schedules are currently published on magnetic media (for transmission to tracking stations via AUTODIN) and on paper. The Network Status and Schedule Change Notification System (NSSCNS), scheduled to become operational during the summer of 1993, will be a first step toward improving this situation. This system will place a network of workstations in all of the MCCs and tracking stations. The system will also be integrated with ASTRO and will provide electronic dissemination of schedules and schedule changes to all users of the schedules. The current scope of development stops short, however, of any form of integration with the MCC data systems. This will present a future opportunity for additional improvements to reduce labor and the possibility of operator errors. Steps can be taken to provide machine readable interfaces directly to the MCC data systems. In MCCs in which security issues do not prevent it, direct electronic interfaces between NSSCNS and the MCC data systems can be provided. In other MCCs, such data transfer can be provided by means of removable magnetic media (e.g., tape or floppy disk).

Although NSSCNS initially will provide software only for schedule dissemination, it will put in place basic network connectivity that would support electronic transfer of schedule inputs directly from the MCCs to the RCCs. Software meeting the wide variety of user needs could be developed to allow easy generation of schedule request data in such a system. Schedule data input interfaces between NSSCNS and the scheduling system itself would also need to be developed.

The level of integration between scheduling and the MCCs can also be improved by the introduction of groupware technology such as network-based on-screen conferencing capabilities. Today, when a hard conflict must be resolved, representatives from the requesting MCCs sometimes meet with a scheduler in the RCC. The scheduler shows the users the schedule constraints on a graphic display, and they work together to find a resolution to the conflict. With the introduction of conferencing software, the scheduler's graphic display could be replicated on workstations in the MCCs. All parties in such a conference are given the capability to make marks and annotations on the display which all other parties can see. (All parties also have voice communication with each other.) In addition to eliminating the need for users to physically meet at the RCCs, such technology can also vastly improve communication when it is not practical for the parties to physically meet, such as when the parties are divided between Onizuka and Falcon.

4. AUTOMATIC SCHEDULING EFFORTS OUTSIDE OF THE AFSCN

Some of the automation improvements mentioned above, such as improving the input and output interfaces of the scheduling process, can clearly be achieved with the application of familiar hardware and software technology currently in use today. The technology required for the process of actually automatically scheduling tasks, however, is not as familiar and in equally widespread use today. Such technology comes from a field known as (not surprisingly) Scheduling Theory. A great deal of work has been done in this field both in academia and industry. The field is often considered to be part of the larger fields of Operations Research or Management Science. Work has been published in this field spanning the period from the 1950s to the present. Textbooks for graduate level courses in the field have been published, and papers presented in the field often form a key part of research conferences.

Today, automatic scheduling approaches are widely used in industrial and manufacturing processes. The literature in the field contains many references to successful artificial intelligence (AI) based scheduling systems at companies such as Intel, Digital Equipment Corporation, Texas Instruments, and McDonnell Douglas. Many commercial software packages for automatically producing schedules are even available at the personal computer and workstation level. (Most of this off-the-shelf software, however, deals with employee scheduling applications that do not map directly to the AFSCN scheduling requirements.)

Within the aerospace industry, automated scheduling approaches have been developed for applications such as mission planning, space shuttle reprocessing, air traffic control, Hubble Space Telescope observations, and Space Station Freedom activity scheduling.

It should not be assumed, however, that there is no development risk associated with an automatic scheduling undertaking. In fact, there have been a number of failed attempts at implementing automatic scheduling throughout the industry. There are a number of reasons cited for these failures, such as the following:

- Lack of sufficient knowledge of the specific scheduling problem being solved
- Poor user interface
- Poor interfaces between the scheduling system and the other systems in its environment
- Lack of attention to the need for making modifications to a schedule once it is already in use.

Lessons learned on previous automatic scheduling efforts will make it possible to take steps to mitigate such risks. Developing automatic scheduling techniques in a prototype manner with close interaction with the actual users, as was done for the ASTRO development, is one of the most effective steps that can be taken to reduce such risks.

5. SUMMARY

Resource scheduling in the AFSCN today is a very complex and time consuming process. As the number of scheduling requests increases, the process will become more complex and time consuming, and the opportunities for human errors will likewise increase. In this new era of tighter budgets and personnel level reductions, improvements in the resource scheduling process will be required in order to continue to meet users' needs with high quality schedules. The automation candidates presented in this article represent a means of achieving such improvements. Moreover, experiences with automating scheduling processes for other applications indicate that the required technology is mature enough for prototyping efforts for AFSCN automatic scheduling to now begin.

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Remote Tracking Station (RTS) Health and Status Monitoring

James A. Hammervold, Loral Space & Range Systems

Current trends characterizing the evolution of the Air Force Satellite Control Network (AFSCN) include increased automation, decreased levels of support personnel, and increased numbers of space vehicle contacts. Reducing manning levels potentially would affect the ability of a Remote Tracking Station (RTS) to perform on-site maintenance as routinely and robustly as before. In addition, the number of preventive maintenance tests and inspections for verifying equipment health and status would be impacted.

The subject study will evaluate the use of current and developing sensor technology to monitor environmental conditions centrally, such as temperature, humidity, air flow, shock, vibration, and power characteristics as they apply to selected RTS equipment and operations areas. Online monitoring and collection of data on environmental conditions will provide the basis for establishing equipment operating limits and for performing trend analyses. Exceeding established limits or normal trends would alert operations personnel of incipient failures and provide sufficient time to investigate the cause, switch to redundant equipment, and/or reallocate network resources prior to any mission impact.

Infusing support environment and trend analysis technology could greatly increase mission uptime and decrease network costs.

Implementing an ability to accurately predict incipient equipment failures would greatly increase the operational availability of the Air Force Satellite Control Network (AFSCN). If the operator could know in advance that a critical component was about to fail, mission operations would be switched to a redundant capability, and maintenance would be called immediately. As a payoff, operational availability would remain consistently high. Indeed one might think a "crystal ball" would be required; however, such an arcane approach is not necessary. Advanced sensing and trend analysis technology is at hand.

Rome Laboratory and several commercial vendors are developing miniaturized environmental sensors that register temperature, humidity, vibration, shock, power quality, and corrosion. These microcircuitry sensors are classified as Time Stress Measurement Devices (TSMDs). The factors measured by these devices play an important and decisive role in determining the useful life of most equipment, including electronic components. Knowing the environmental conditions under which the equipment is operated provides essential insight into the equipment failure mechanisms.

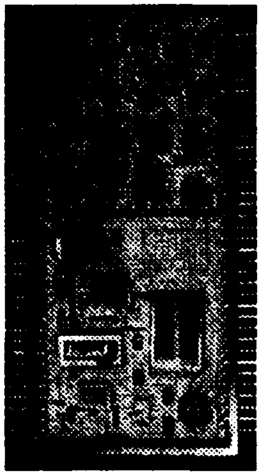

Figure 1: Honeywell Micro Time Stress Measurement Device (TSMD) (1" X 2")

A proof of concept study for monitoring trends and predicting failures in the Air Force Satellite Control Network (AFSCN) equipment is being performed by Loral Space & Range Systems (LS&RS). The "Remote Tracking Station (RTS) Health and Status Monitoring" study is sponsored by the CWIA division of the Space and Missile Systems Center (SMC). The objective of the study is to provide a health and status monitoring capability for critical AFSCN RTS equipment to support incipient failure prediction and the determination of failure modes. This includes both mission and critical support equipment/systems, such as high power transmitters, receivers, antenna drive systems, as well as air conditioning, power, and security systems.

This study will involve the use of progressive diagnostic techniques and processes to predict failures, thus increasing operational availability and decreasing maintenance actions. These overall goals, in fact, correlate directly with the goals of the Air Force Reliability & Maintainability 2000 initiative. The study approach is to continuously monitor operating conditions of critical RTS equipment using autonomous monitoring techniques. Initially, the environmental data will be captured for candidate equipment at a designated test site. Information will be selectively stored, time-stamped, and transported to a data processing workstation for failure prediction analysis. Once failure symptoms and modes on target RTS equipment have been determined, an intelligent monitoring capability can be implemented.

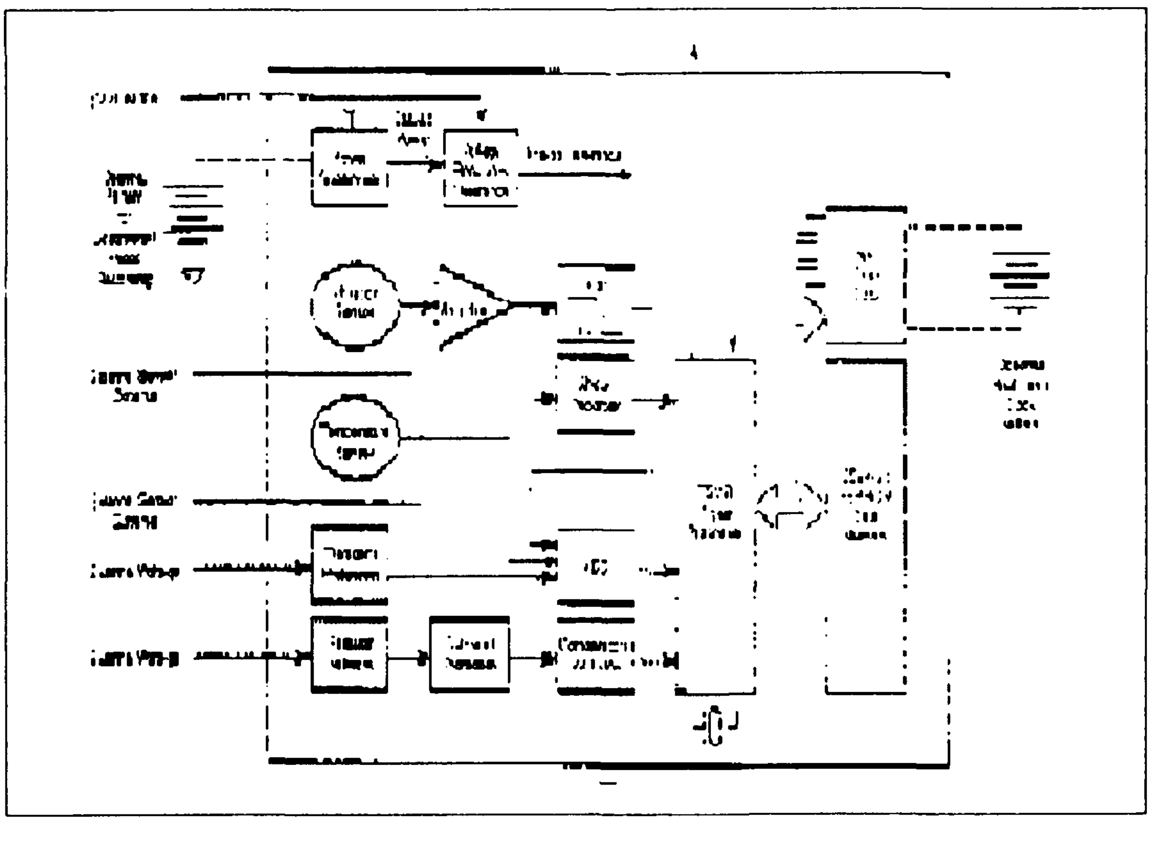

Figure 2: Functional Diagram of the Micro TSMD

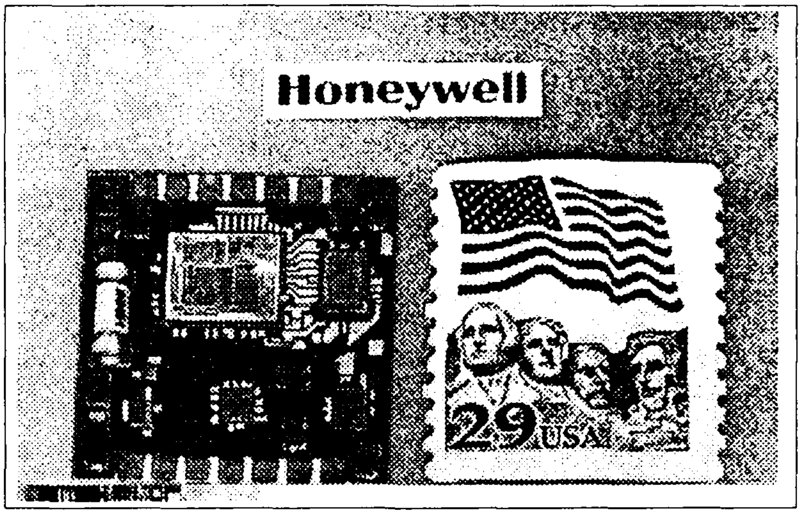

Figure 3: Honeywell Environmental Stress Monitoring Device (ESMD)

As a follow-on effort, data collected simultaneously from both the operations environment and built-in-test equipment might be fed into an intelligent, on-site monitoring capability which could alert a central node of impending equipment failures. (Note: System built-in-tests, generally conducted during routine maintenance, can only be conducted on a non-interference basis with respect to mission operations.) As such, the collective scenario will require the composite strengths of preventive, predictive, and proactive maintenance techniques in a coordinated and systematic effort to eliminate system downtime at the RTSs.

This initiative will focus on uncovering incipient failures and the elimination of failure causes rather than post-failure diagnosis and field replacement of failed equipment which was typical of earlier maintenance practices. Using preventive maintenance inspection (PMI) techniques, equipment was replaced when degraded or at breakdown; standard PMI schedules were established following the collection and availability of sufficient field history data. Although preventive maintenance significantly reduced failures, the cost of unnecessary replacements and the risk of introducing new problems during PMIs are no longer considered acceptable.

Pivotal to this effort are capabilities provided by other R&M initiatives, including the Reliability Maintainability Availability (RMA) Engine. In a complementary fashion, the RMA Engine will provide the AFSCN equipment configuration in block diagram format. Using block diagram format, the RTS Health and Status (H&S) capability will display the status and location of critical AFSCN equipment, indicating the equipment status as red (actual outage), yellow (pending outage), or green (no outage). This would alert network operators to possible/actual equipment failure, thus improving the operator reaction time to reallocate resources.

Among the payoffs for an implemented RTS H&S capability are:

- Increased operational availability
- Decreased maintenance requirements to an as-needed basis
- Continuous real-time monitoring
- Cross-correlation of all potential/actual system failures, including a real-time interface with BIT capability
- Reduced "Can Not Duplicate (CND)" and "Retest OK (RTOK)" events since a record of the operating conditions at the time of occurrence should greatly enhance event resolution
- Assured warranty verification data with the collection of actual equipment reliability statistics
- Enhanced pipeline flow and cost control tracking measures for spare parts and inventories

As such, with a future implementation of the RTS H&S capability, the AFSCN would experience substantial improvements in the operational availability and maintainability of its sites. Moreover, this capability would support steady improvements in AFSCN operational availability and provide the basis for building a comprehensive Reliability and Maintainability (R&M) toolset for evaluating engineering design changes.

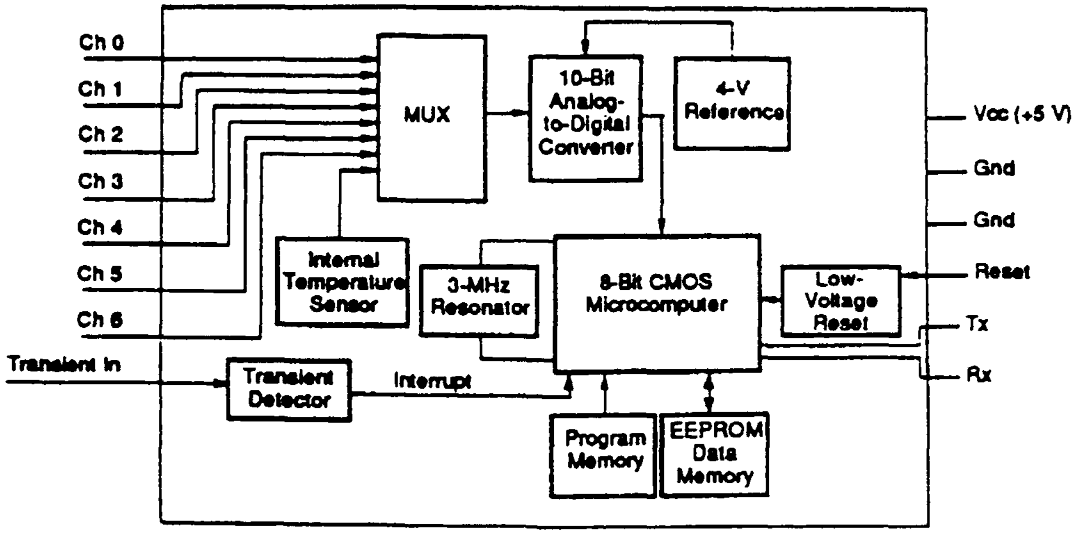

Figure 4: Functional Diagram of the ESMD

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Software Metrics and Tools

Darryl Jefferson, C&DP/Paramax

This paper assesses current software metric practices used in various phases of the Air Force Satellite Control Network (AFSCN) software development life cycle. It also identifies technologies that could potentially aid AFSCN personnel in improving software performance, quality, and reliability through the use of new tools and measurement techniques.

INTRODUCTION

Software metrics are a standard way of measuring the efficiency of the software development process. Metrics can measure specific attributes of software such as lines of code and performance deficiencies.

The Command and Data Processing contract (C&DP) has identified two principal categories of metrics: System Performance and System Test. This paper describes the data collected thus far in these two categories.

SYSTEM PERFORMANCE METRICS

The primary function of software system performance metrics is to measure the efficiency of the processing of information. Additionally, performance metrics can indicate regressions due to system or subsystem modifications. Such metric data should focus primarily on overall system performance rather than on one particular characteristic. Typical characteristics measured to evaluate software performance include:

- CPU utilization: Percent of the central processing unit (CPU) used during execution of an application program
- Real storage utilization: Amount of real storage required by the application and the operating system
- Channel path utilization: Congestion observed during testing
- Input/output activity rate: Frequency at which data are updated
- Virtual storage utilization: Amount of virtual storage required by the application.

The AFSCN uses a variety of tools to collect data on performance characteristics. These tools are described below:

- The Resource Management Facility (RMF) monitors CPU usage, virtual storage utilization of each address space, and input/output (I/O) display activity rates. Data are sampled every 1 to 10 seconds and reported every 60 seconds.

- The Generalized Trace Facility (GTF) operates on a mainframe and provides the user with specific information on Command and Control Segment (CCS) and Mass Virtual Storage (MVS) CPU data, I/O data, and module link information. The GTF tool is only invoked and data collected if CPU capacity is 60 percent or lower. The tool is activated during selected intervals and is run for 60 seconds. GTF measurements are considered to be accurate because GTF computes and factors out its own overhead.

- The Real Time Executive (RTX) data reduction tool is a delogging tool that provides continuous performance analysis of the CCS system for the entire CCS job. CONSOLE, a tool used in conjunction with GTF and RMF timestamps information with interaction that takes place between CCS jobs. This allows the user to see the time of each step of the plan.

- The Resource Monitoring Tool (RMT) provides information on the use of each RTS buffer pool and further provides DMIO and DATAFOO reports which show I/O activity to Virtual Storage Access Methods (VSAM) files.

- The Statistical Analysis System (SAS) is a post-processing tool that compiles data into a comprehensible format. SAS is used to post-process data derived from GTF and to extract certain information from RMF data. SAS can also extract data from RTX logs.

- The Jovial Probe Facility (JPF) probes are one of the most commonly used tools for extracting data and providing a variety of detailed application data. Depending on the complexity of the test case, however, JPF provides more data than is necessary to verify the test case. This information includes file access times, scenario confirmation and analysis, function elapsed time measurements, and buffer management analysis.

- The Omegamon tool, which operates from a mainframe, provides specific data on system resources.
- The Local Area Network (LAN) Analysis Model is a PC-based spreadsheet used to monitor LAN traffic throughput and arrival for future LAN configurations.
- A variety of Unix tools used on the Telemetry Front End Workstation provides specific information on Paging activity, real and virtual memory utilization, and network file system activity.

CURRENT TEST METRICS

The C&DP Development/Sustaining Engineering (D/SE) organization is responsible for collecting software test metrics on the C&DP contract. Within the D/SE process, measurements are taken throughout the cycle; measurement begins in model planning, where an assessment of complexity factors is made and continues through the final stage of functional configuration audit (FCA)/physical configuration audit (PCA). Measurements are taken at various stages throughout this process and different types of metric data are extracted for analysis. Some of the categories of metrics are described below.

Efficiency is measured in terms of the time expended to develop the test plans and test descriptions. This provides the user with a comparison of time versus complexity of the test case.

Quality is measured by the number of comments, redlines received per test case, number of reruns needed, number of changes to document after release, and the percentage of test summaries completed within 48 hours.

The **schedule** metric measures on-time delivery of test documentation (test plans, procedures, etc.).

Productivity is measured in terms of the tester's productivity in the lab (test time) and the time it takes to generate a test report. Finally a predetermined rate chart is used to calculate whether a test case or test review meets its precalculated time to completion.

Three forms of metric analysis can take place throughout integration testing and computer software configuration item (CSCI) testing:

- **Casual** analysis consists of monitoring the number of redlines, comments, reruns, and on-time delivery of documents.
- **Trend** analysis monitors test plan development and description times, tester productivity, percentage of run folders generated, number of automated test cases, and test report development time.
- **Status** analysis is monitored in terms of whether the proposed delivery time, the projected test plan execution time, and document turnaround times are met. The above collected data may be computed independently or in various combinations.

NEW AND EMERGING TOOLS

Current testing procedures in the AFSCN are manually intensive. Manual processes in testing can cause lost time and occasionally erroneous test results. Automating the testing process is clearly the desired path towards meeting reduced cost and increased quality and reliability goals. Automated test tools reduce the amount of human interaction, which ultimately will reduce the number of errors introduced in the testing process.

Automated testing will reduce the amount of data humans must process, which will allow testers to devote additional time to building a more intelligent and comprehensive test case. A few of these tools are described below.

The Development Automated Repetitive Testing System (DARTS) is a mainframe-based test tool. Designed for use in the AFSCN, it permits replaying test cases with precise repeatability for comparison against output data. The ultimate result is a reduction in the cost of testing software with the quality consistent with or higher than manual testing procedures.

Available commercial tools, such as Software Research's Software TestWorks (STW), provide an integrated set of tools that assist in regression testing and test planning. These tools support testing and quality control enhancement throughout the entire life cycle of software development.

Automated measurement techniques and tools are being used to support the improvement of software. The Amadeus Measurement Driven Analysis and Feedback system is sponsored by the Defense Advanced Research Projects Agency (DARPA) to support work on Software Technology for Adaptable Reliable Software (STARS). Amadeus empirically guides the software development process by integrating in-process measurements that show where improvements can be realized. Ultimately, the intent is to improve large scale system software through empirical analysis. Another measurement tool called METRIC, produced by Software Research Inc., is a metrics software generator and processor. This tool measures the size and complexity of software code to determine the areas that need the most developmental attention. Metrics support code written in Ada, C, C++ and Fortran.

Measuring quality is another facet of software that is moving toward automation as a means of improving development process. The Quality Evaluation System (QUES) is a tool sponsored by Rome Labs and developed by Software Productivity Solutions, Inc. This tool defines the framework of software quality from a user's point of view. QUES automates the quality measurement process to make software development more feasible in terms of costs. In addition, it unburdens the users from having to sort through massive amounts of data. QUES produces finished reports and analysis which are easy for users to comprehend.

Determining reliability of software runs hand in hand with quality determination. There are models, design methods, and techniques for ensuring reliable software development; however, no real solution can be derived by one particular method. Determining software reliability can vary from project to project depending on how reliability is defined. Reliability is also another function that is being automated in the software development life cycle.

Computer-Aided Software Reliability Estimation system (CASRE) is one tool that is under development for assessing the reliability of software. The intent of the reliability system is to give the engineer information that identifies the best model or models that holds the solution to his or her needs.

CONCLUSION

In assessing the use of measurement data for various AFSCN characteristics, it was found that present software practices focus on maintaining current levels of software performance rather than on improving these levels. Metric data collected during testing appear to vary with the complexity of the test case. The quality of metrics appears to rely on the quantity of the comments or redlines rather than on the quality of the comments which are significant. Analysts and engineers would benefit from using tools that reduce the amount of analysis data. Eliminating the large amount of data derived from test cases would give the analyst just the data needed to verify the test case.

The AFSCN would benefit from having a base of generic (reusable) software available, adding state-of-the-art software tools and techniques to meet its software improvement goals. Tools chosen on a case-by-case basis depending on the particular function (e.g., requirements analysis or quality analysis) would help the AFSCN meet cost reduction goals and also form a viable path towards achieving ultimate software performance and improvement in the AFSCN.

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Wide Area Network (WAN) Communications Technologies - Evolution - Part 1

WAN Technologies:
From Circuit Switching to Fast Packet Switching and AFSCN WAN Technology Forecasts

Terry Balanesi, C&DP/Paramax
Nicholas Phan, C&DP/Paramax

This two part article covers the evolution of Wide Area Network (WAN) technology from the first digital network, the T1 system, to the future developments towards Broadband Integrated Services Digital Network (BISDN). In Part 1, the article introduces WAN technologies and discusses two fast circuit switching networks: 1) T1 systems and 2) Integrated Services Digital Network (ISDN). In Part 2, which will appear in a subsequent technical report, fast packet switching networks and their associated technologies will be explored. These are: 3) Frame Relay, 4) Switched Multimegabit Data Services (SMDS), and 5) BISDN (which includes an explanation of Asynchronous Transfer Mode (ATM) and Synchronous Optical Network (SONET)). Additionally, Part 2 gives a forecast of how future communications technologies can be infused into the AFSCN.

INTRODUCTION

One of the fastest growing technologies in the computer high technology industry is the computer communications field. The introduction of fiber optics has brought with it new and exciting technologies that will utilize the full potential of this communication medium. This article introduces the communications technology background to the Air Force Satellite Control Network (AFSCN) by describing the technologies and methodologies that continue to influence the communications field in wide area networks (WANs). The method used to explore these basic WAN technologies is to describe the historical evolution from the first digital network of the telephone companies to the expectations offered by future fast packet-switched and fast circuit-switched networks. This method of exploring these technologies also shows their relationships to each other.

The AFSCN can be described as a private, dedicated, circuit-switched WAN based on improvements of the T1 system technology. Section 4.2.1 (System Performance) of the AFSCN Operational Requirements Document (ORD) (First Coordination Draft) dated the 23 February 1993 addresses a specific problem with the AFSCN WAN and identifies the value of this article. Currently, the AFSCN WAN maintains communications links sized to accommodate the maximum bandwidth needed. The cost for maintaining these types of dedicated communications links is seen as no longer supportable. The technology now exists that allocates a communications link only the bandwidth that is needed (bandwidth on demand).
This new technology can be utilized in one of two ways in the AFSCN. The first way is to convert the existing AFSCN WAN technology over to the new technology. This conversion represents a major expense to the AFSCN. The second way to make use of this new technology is to have the AFSCN WAN incorporate the use of the new technology public networks being developed. This method simply requires purchasing equipment that will interface with the new public networks and represents an easier transition to infusion of the new technology.

This article explains the new technologies as they have evolved, and identifies the public networks that are being developed. Introducing these new technologies and public networks here can benefit the AFSCN community by providing valuable information for future decisions that must be made concerning AFSCN communications. The last section of Part 2 of this article contains an aggressive attempt to forecast the infusion of these new technologies into the AFSCN WAN.

WIDE AREA NETWORK COMMUNICATIONS TECHNOLOGY OVERVIEW

The communications field has divided its architectural view of the world into three distinct groups: local area networks (LANs), metropolitan area networks (MANs), and WANs. The definition of these groups uses two key points: geographical area and data transmission rates. However, data transmission rates have diminished as a distinguishing factor with the development of new communications technologies. Generally, LANs are limited to a geographical area of a building or group of buildings. Likewise, MANs are usually contained within a metropolitan area. The main topic of this article deals with the new technology that is being developed for use in WANs. The WAN technology, with its increased data transmission rates (and, therefore, its increased bandwidth) will have the biggest impact on world-wide communications in the near-term and mid-term future. The AFSCN will find the application of this technological growth to be of greatest interest.

COMMUNICATIONS NETWORKS SWITCHING

Communications networks switching consists of an interconnected (by communications links) collection of nodes, in which data are transmitted from a source node to a destination node by being routed through the network of nodes. A node can represent data terminal equipment (DTE), data switching equipment (DSE), or data circuit terminating equipment (DCE). The DTE generally describes the end user machine (computer or terminal). The DCE's function is to connect the DTE into the communications link. The DSE refers to the switch that allows the DTE to use more than one communications link to communicate with multiple end users. The two types of communications network switching explored here are circuit-switched networks and packet-switched networks.

Circuit switching is the process of establishing and maintaining a communications physical circuit between two or more users on demand and giving these users exclusive use of the communications circuit until the connection is released.

Packet switching is so named because the user data are divided into pieces, or packets. These pieces or packets have protocol control information (headers) placed around or in front of the user data and are routed through the network as independent entities. The traditional, predominant interface standard for packet switching networks is the International Telegraphy and Telephony Consultative Committee's (CCITT's) X.25 standard. This X.25 standard can be described using the International Organization for Standardization's (ISO's) seven-layer Open Systems Interconnection (OSI) model. The X.25 standard introduces the concept of the virtual circuit. This method establishes a logical connection through the network from the source DTE to the destination DTE before any packets are sent. This is done by associating each channel (link) at each of the nodes with the virtual circuit. Three other key features of the X.25 standard that will be discussed in relation to WAN technology are:

- Call control packets are used for setting up and clearing virtual circuits. These control packets are carried on the same virtual circuit as data packets. This type of signaling is called inband signaling.
- The ISO model network layer performs the multiplexing of the virtual circuits.
- Flow control and error control mechanisms are at both the ISO model data link layer and network layer.

In addition, the X.25 network must keep a table of current states for each virtual circuit at each node between the source node and the destination node of the network. All of this overhead is justified when there is significant probability of error on any of the communication links in the network. The network overhead described here has given rise to major developments in packet switching technology. These major developments are described in the fast packet switching evolution section contained in Part 2.

MULTIPLEXING METHODOLOGIES

Multiplexing allows multiple data channels to be combined on a single transmission medium. This allows for a more effective use of the total bandwidth of a communications link.

In frequency division multiplexing (FDM), the transmissions from multiple users are sent simultaneously across the communications link. Each user is allocated a fixed portion of the frequency spectrum. A number of users' signals can be carried simultaneously if each signal is modulated onto a different carrier frequency (channel) and these carrier frequencies (channels) are sufficiently separated so that the bandwidths of the signals do not overlap. Each carrier channel is assigned a different frequency to prevent interference from other channels, and each channel is separated with unused portions of the frequency spectrum called guardbands.

Time division multiplexing (TDM) provides a user the full channel capacity, but divides the channel usage into time slots. Each user is given a slot and the slots are rotated among the user channels.

The conventional TDM wastes the bandwidth of the communications link for certain applications because the time slots are often unused. Vacant slots occur when an idle link has nothing to transmit in its time slot. Statistical TDM dynamically allocates the time slots among the active communications links and thus eliminates vacant slots.

FAST PACKET SWITCHING DEFINED

Fast packet switching (FPS) removes the error checking and flow control that are present in the ISO model data link layer protocols of older packet switching networks. This simplified data link protocol allows faster packet switches the capability to take over the routing of the packets through the network. The capabilities of the switches rely on: 1) the improvement of the physical medium (i.e., fiber optic cables) that reduces the probability of packet error or loss, and 2) a large increase in available bandwidth.

FAST CIRCUIT SWITCHING DEFINED

Fast circuit switching relies on the high-speed circuit switch improvements combined with the improvement of the physical medium (i.e., fiber optic cables) and its large increase in available bandwidth.

FAST CIRCUIT SWITCHING EVOLUTION

Fast circuit switching technology has evolved from the first digital network technology, the T1 system. The T1 technology first became commercially available in 1977 and has sparked an evolution of improvements to the early digital system. The fast circuit switching technology has been developed by the following improvements: 1) faster circuit switches that set up a call circuit in less time, 2) multiplexer technology that has the capability of multiplexing an increasing amount of circuits, and 3) fiber optic cabling, which is slowly making its way into the infrastructure of the existing telephone digital network, which cleans up the signal so that error checking no longer remains a concern of the network. Another improvement that is part of this evolution is the attempt to eliminate the need to convert from analog-to-digital and digital-to-analog in the existing telephone digital network. This would be accomplished through the adoption by all regional Bell operating companies of a national Integrated Services Digital Network (ISDN) standard that allows only digital voice and data input to the telephone network.

THE T1 SYSTEM FAMILY

With the advent of analog-to-digital conversion and cost-effective pulse code modulation (PCM) techniques, AT&T and the Bell system began to implement digital voice systems in the early 1960s. Designated the T1 carrier, these early systems were initially constructed to connect telephone central offices. The T1 system is designed around a 1.544 million bits per second (Mbps) data transmission rate, which in the 1960s was the highest data transmission rate that could be supported across twisted copper wire pair (or twisted pair) for an approximate distance of 1 mile (6,000 feet). By spacing the manholes in large cities at this approximate 1-mile distance, a convenient means to replace the analog amplifiers with digital regenerators was created. The term T1 was devised by the telephone company to describe a specific type of equipment. Today the term T1 is used to describe a general carrier system, a data transmission rate, and numerous data framing protocols.

The T1 system (see Figure 1) is based on time division multiplexing 24 users on one physical circuit. The system uses a data service unit (DSU) / channel service unit (CSU) to accomplish the analog-to-digital conversion and the multiplexing. The DSU converts DTE signals into bipolar (two polarities which represent a binary zero and a binary one) digital signals. In addition, the DSU performs clocking and signal regeneration on the digital channel. The CSU performs the following functions: 1) line conditioning (equalization), which keeps the signal's performance consistent across the channel bandwidth, 2) signal reshaping, which reconstitutes the binary pulse stream, and 3) loopback testing.

Since the T1 system predates the ISO model, no direct correlation exists between the two. However, the T1 system can still be described using the ISO model. The T1 system uses frames for data transmission and control across the network. In terms of the ISO model, the only layers involved in the T1 system are the physical layer and the data link layer. These T1 frames use various techniques to embed control and error checking employed between two data transmission nodes. After years of development, the Extended Super Frame (ESF) was introduced to address

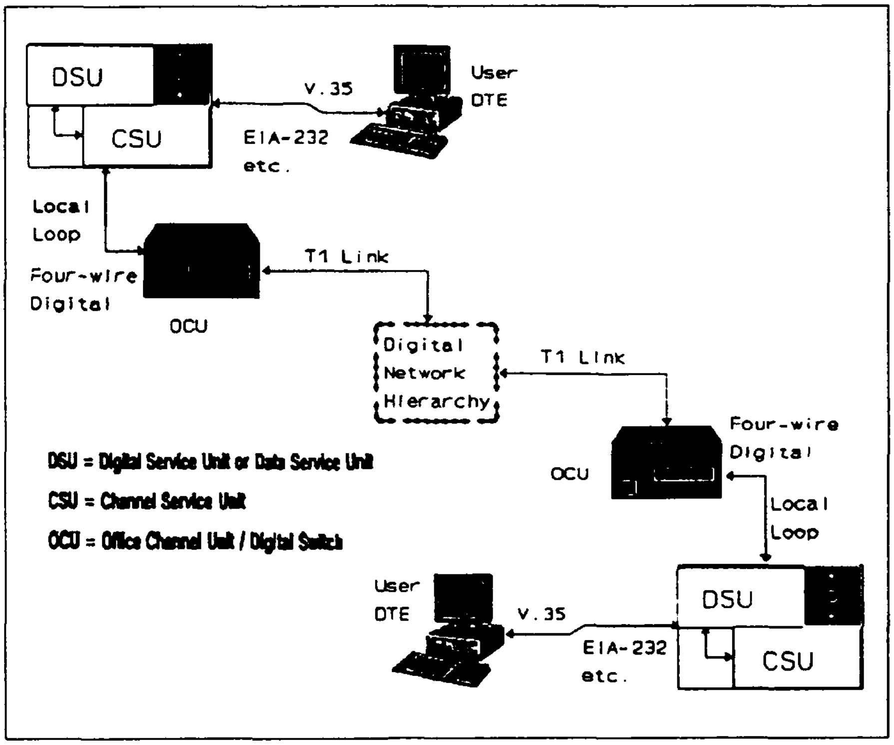

Figure 1: Digital Circuit Structure

several problems inherent in previous T1 frame formats. The ESF provides additional signalling capabilities, more diagnostics, and error detection. The data link protocol of the T1 frame can utilize a High-level Data Link Control (HDLC), which is an ISO bit-oriented line protocol specification, or a subset of HDLC such as Link Access Procedure, Balanced (LAPB). The AT&T ESF uses a simplified LAPB.

The T1 system has become one of the most widely used high-capacity systems for transmission of both voice and data. In January, 1984, AT&T introduced its ACCUNET T1.5 service that provided sufficient bandwidth to handle data, voice, and video simultaneously.

Fractional T1 permits the network user, whose traffic volume does not justify the need for a full T1 link, to buy DS0 (64 Kbps) lines individually.

Table 1 identifies the current definitions of T1 systems using copper twisted pair. Table 2 identifies the definitions of T1 systems using fiber optic cables. There has been a blending of the early fast packet technologies over the existing public circuit-switched telephone T1 digital network. This blending of technologies will probably continue with the introduction of T3 circuits (see below). However, the migration towards BISDN and the use of photonic technology such as SONET will severely reduce the T1 system market.

High-Rate Digital Subscriber Line (HDSL) is a high-priority research project being conducted by Bellcore (Bell Communications Research). By 1992, this project will enable local telephone companies to offer switched and dedicated T1 services over existing copper local loops without repeaters.

High-Speed Circuit Switching (HSCS) data service provides dial-up digital data transmission at T1, T3, and higher rates, with pricing based on usage. Since HSCS involves several seconds of dial-up time, this service is ideal for companies that transmit data over extended periods of time (several hours) and do not require instantaneous access.

Table 1: T1 System Family Using CopperTwisted Pair

System Name	Number of Channels	Data Transmission Rate
T1	24	1.544 Mbps
T2	96	6.312 Mbps
T3	672	44.736 Mbps
T4	4,032	274.176 Mbps

Table 2: T1 System Family Using Fiber Optics

System Name	Number of Channels	Data Transmission Rate
FT3	672	44.736 Mbps
FT3C	1344	90.524 Mbps
FT-4E-144	2016	140.0 Mbps
FT-4E-432	6048	432.0 Mbps

INTEGRATED SERVICES DIGITAL NETWORK

With the emergence of digital transmission and digital switching came a revolutionary concept that these two functions could be integrated to form an Integrated Digital Network (IDN). This concept was in contrast to the functionally separate organizations that designed and administered the transmission and switching systems in previous telephone networks. This evolution toward the IDN has been driven by the need to provide economic voice communications. However, the resulting network has been shown to be well suited to meet a variety of digital data service needs. Therefore, the IDN will combine the coverage of the geographically extensive telephone network with the data-carrying capacity of the digital data networks in a structure referred to as ISDN. The Integrated Services Digital Network has been developed in a group of recommendations by the CCITT. This group of recommendations features digitalization of existing telephone networks, existing and anticipated telecommunication services, end-to-end signaling, and standardization of equipment and protocols.

Since one of the goals of ISDN is to use the existing telephone network infrastructure, much of the technology that exists in the present telephone network digital subscriber loop using T1 system technology is described in the T1 system family section. ISDN will support a completely new physical connector (or interface) for users (see Figure 2), a digital subscriber loop, and a variety of transmission services. The new interface (see Figure 3) supports a basic service consisting of three time division multiplexed chan-

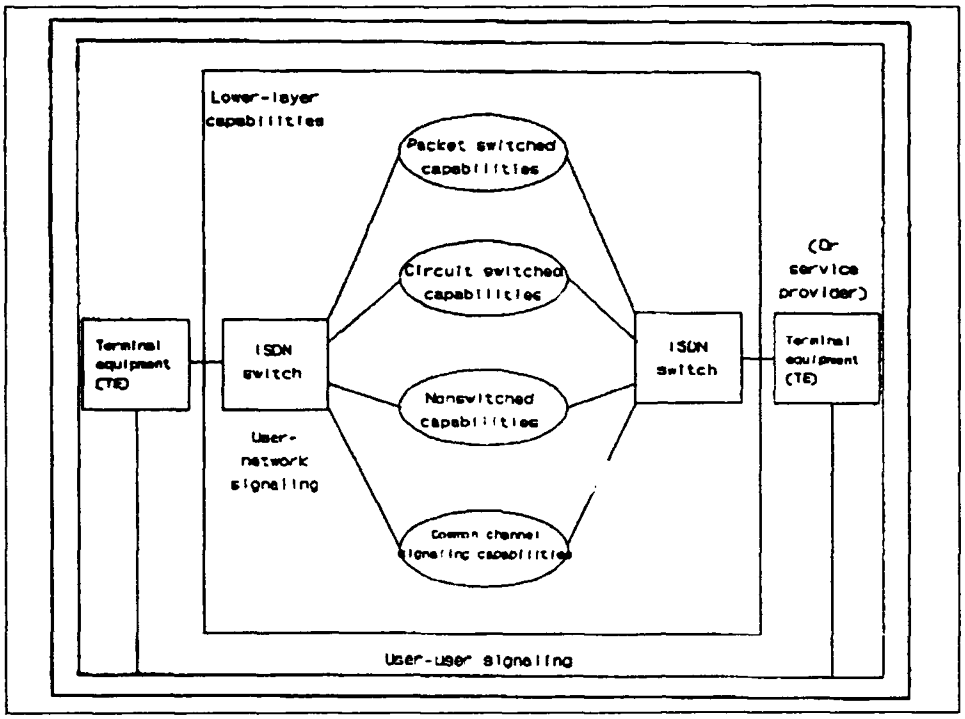

Figure 2: ISDN Architecture

nels: two channels that have data transmission rate capacities of 64 thousand bits per second (Kbps) and one channel that has a data transmission rate capacity of 16 Kbps. In addition, a primary service will provide multiple 64 Kbps data transmission rate channels. The subscriber loop provides the physical signal path from the user to the ISDN central office. This subscriber loop must support full-duplex digital transmission for both the basic and primary data transmission rates. Initially, much of the subscriber loop plant will be twisted pair. As ISDN evolves, it is anticipated that fiber optic cable will be used more frequently. The ISDN central office will connect the subscriber loops to the ISDN and provide access to a variety of ISO model lower layer (layers 1 through 3) transmission functions. These transmission functions include packet switching, circuit switching, and dedicated circuits. The user will also have access to common channel signaling, which is used to control the network and provide the call management.

The ISDN central office to ISDN user connection (known as a pipe) will carry a number of communications channels. The number of channels, which represents the capacity of the pipe, will vary between users. Three types of channels are used in constructing the transmission structure or pipe of any ISDN access link. The channel types are: the B channel with a data transmission capacity of 64 Kbps, the D channel with a data transmission rate of 16 Kbps or 64 Kbps, and the H channel with a data transmission capacity of 384 Kbps, 1536 Kbps, or 1920 Kbps. The B channel is the basic user channel. This channel is used to carry digital data, digitized voice, or a mixture of lower data transmission rate traffic including digital data and digital voice encoded at a fraction of the 64 Kbps data transmission rate capacity. Three kinds of connections can be used over a B channel. These connections are: packet-switched, circuit-switched, and semi-permanent or leased line. The D channel serves two important purposes. First, the D channel carries the signaling information to control circuit-switched calls on the associated B channels at the user interface. The D channel is used to set up calls on all of the B channels at the user interface (this process is known as common channel-signaling). Secondly, the D channel is used for packet switching or low speed telemetry at times when no signaling information is needed. The H channel is provided for user information that requires higher data transmission rates. The user may use the H channel as a high speed trunk or may subdivide the channel using time division multiplexing.

The ISDN protocol architecture is shown in Figure 3. ISDN currently has two ISO physical layer interface specifications: the basic rate user-to-network interface and the primary rate user-to-network interface. In both interfaces the ISO physical layer primitives are defined and used to activate and deactivate the physical interface and, thus, provide service to the ISDN ISO data link layer.

The CCITT ISDN recommendations reference four important data link protocols for consideration: LAPD, LAPB, I.465/V.120, and frame relay. Initially, the principal emphasis by the CCITT was to define a data link control protocol for the D channel. This protocol, known as LAPD, is used for communication between the user and the network. All D channel traffic employs the LAPD protocol. The LAPD protocol is a subset of the LAPB protocol, which, as stated earlier, is a subset of the HDLC protocol. The LAPB protocol was also included in the X.25 standard

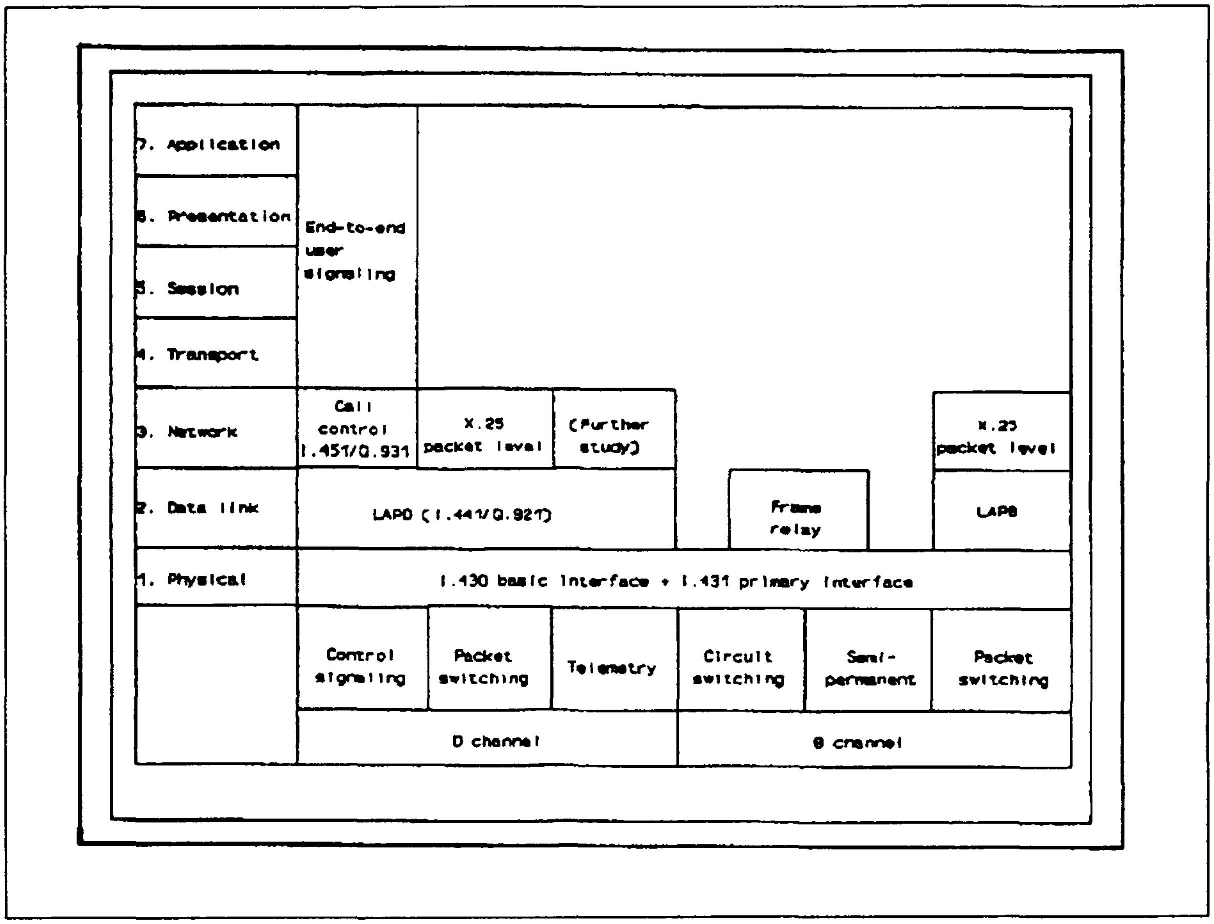

Figure 3: ISDN Protocol Architecture at the User-Network Interface

for packet networks and is used in conjunction with the X.25 network layer on B channels to provide packet switching support for ISDN users. A circuit-switched connection has an end-to-end circuit between two users. The users are free to use any data link control protocol. However, two ISDN-related data link control protocols have been standardized: I.465/V.120 and frame relay. The I.465/V.120 is a 1988 CCITT recommendation on terminal adaptation based on a data link protocol similar to LAPD. This data link control protocol allows for the multiplexing of multiple logical connections between two users over a single B channel or H channel circuit. Frame relay takes the I.465/V.120 concept one step further. Frame relay is described in the Frame Relay section in Part 2 of this article.

The ISDN network layer protocol is the key to ISDN call control. The ISDN network layer protocol deals with circuit-switched services calls, packet-switched services calls, and user-to-user signaling not associated with a circuit switched call.

ISDN will provide a wide variety of services such as telephone, leased telephone circuits (information retrieval), music, packet-switched data, circuit-switched data, leased data circuits, telemetry, funds transfer, mailbox, electronic mail, alarms, telex, teletex, videotex, facsimile, surveillance, television conferencing, teletext, videophone, and cable television distribution. These services can be grouped under four service headings: telephony, data, text, and image.

While ISDN has been available in a limited capacity to a few large companies over the last 5 years, differences between the Regional Bell Operating Companies (RBOCs) have prevented communication between the ISDN users. In early 1991, the telecommunications industry moved toward overcoming this problem by agreeing on a new nationwide ISDN standard. Computer companies and other equipment manufacturers have been busy developing products that would use this new technology. In Northern California, companies such as Combinet Incorporated of Sunnyvale, Pacific Bell, Northern Telecom, IBM, and Lawrence Livermore National Laboratory have been using ISDN for telecommunicating, video teleconferencing, and advanced faxing. Still, two of the seven RBOCs, Southwestern Bell Corporation and U.S. West Incorporated, have quietly decided not to use the new ISDN standard for the basic type of ISDN service and chosen to use their own standard. To add to the problem, a rift still persists in the telephony industry over how fast the RBOCs intend to modernize to digital networks and how much the RBOCs will charge for the new ISDN services.

SUMMARY

Part 1 of this two part article has introduced the key terminology for WAN technologies and investigated the major fast circuit switching networks. Part 2 identifies and investigates the current and future fast packet switching networks and their associated technologies and protocols. In addition, the infusion of these fast circuit switching and fast packet switching into the AFSCN is investigated.

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Modeling the Air Force Satellite Control Network (AFSCN)

Using Modeling To Support AFSCN Decision Makers

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Modeling and Simulation (M&S) is becoming an increasingly important technology in the DoD system acquisition process. Emphasizing the importance of M&S, the Defense Modeling and Simulation Office was established in 1991 to coordinate M&S activities across the DoD. Further, the Director, Defense Research & Engineering has included Synthetic Environments, which employ and integrate M&S, as one of seven Science and Technology thrusts.

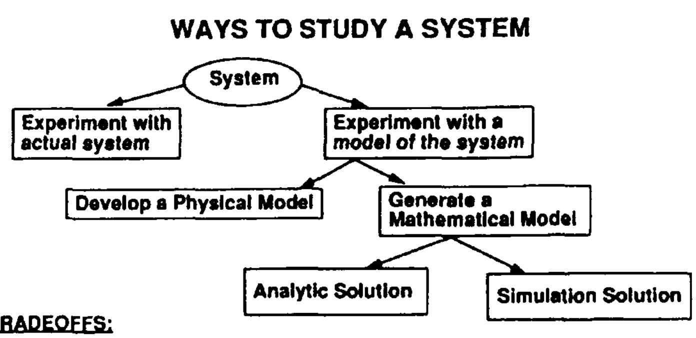
This paper briefly discusses the technology of M&S and the role of M&S in the Air Force Satellite Control Network (AFSCN). The primary focus is a proposed network level model, NEMO, that employs integrated, hierarchical, variable-resolution modeling technology. The result is a flexible, robust modeling capability at various abstraction levels to support a variety of AFSCN analyses. In addition, NEMO could be a component model in a Synthetic Environment used to train warfighters and support system acquisitions.

INTRODUCTION

Modeling and Simulation (M&S) is becoming an increasingly important technology in the DoD system acquisition process. M&S plays a key role in the new DoD emphasis on demonstration of technology maturity and operational relevance prior to the start of and at key milestones and decision points in the process. In addition, M&S is being applied to enhance the performance of numerous functions, including training and readiness, concept of operations development, contingency planning, operations, after mission review and historical analysis.

Emphasizing the importance of M&S, the Defense Modeling and Simulation Office (DMSO) was established in 1991 to coordinate M&S activities across the DoD. Further, the Director, Defense Research & Engineering (DDR&E) has included Synthetic Environments, which employ and integrate M&S, as one of seven Science and Technology thrusts.

Given this DoD focus on large-scale simulation and integration of models, this paper examines M&S with regard to the AFSCN. Our primary focus is a network level AFSCN model. We discuss the needs for such a model, its benefits, development approach and application to support Air Force decision making.



TRADEOFFS:

Approach	Advantages	Disadvantages
Experiment with actual system	Very accurate	Ties up system, cannot be used to model future possibilities
Develop a physical model	Good accuracy, can depict ("what ifs")	Expensive and inflexible
Generate an analytic solution	More exact solutions for the set of assumptions	Assumptions may be unrealistic and hard to understand
Generate a simulation solution	Highly flexible, more understandable	High precision requires large amounts of computer resources

Figure 1: Ways to Study a System

MODELING AND SIMULATION TECHNOLOGY

Computer modeling and simulation is the technology of manipulating and evaluating a computerized representation of some real-world entity to mimic or predict its behavior. To understand how simulation modeling fits within the "world" of modeling and how it differs from other types of modeling, see Figure 1, "Ways to Study a System." One of the primary advantages of simulation modeling is flexibility. Because of its flexibility, simulation modeling supports the study and analysis of extremely complex systems with complex interactions between components.

The major disadvantage of simulation modeling is that tradeoffs must be made between model fidelity (how closely the modeled behavior matches the real-world system's behavior) and execution speed. Even with today's faster processors, model builders usually must choose between modeling a component or subsystem at high fidelity or modeling the whole system at low fidelity. The disadvantage of the former is that the model cannot be evaluated from a system perspective and side effects of unmodeled components can be missed. The disadvantage of the latter is that oversimplification or abstraction of behavior can lead to invalid or incorrect results.

The most promising solution to the problem, being pursued throughout the research community, is an integrated, hierarchical, variable-resolution model (IHVRM). The IHVRM provides the "best of all worlds," a high level model that executes rapidly, but zooms in on lower level, more detailed models when required. At Rome Laboratory, for example, a hierarchical approach looks promising for an application focused on hostile target identification [Sisti]. The approach integrates detailed, engineering models that can be "zoomed in on" from a higher level engagement model when more detail is required to support the overall simulation.

Although the IHVRM approach looks promising, there are research issues to be resolved. Ideally, the model would incorporate mechanisms that would automatically identify the portions of the model that contribute most significantly to the results, perform sensitivity tests to determine when results are misleading or incorrect, and "zoom in on" higher fidelity models as required to preserve the integrity of the model output.

M&S IN THE AFSCN

The AFSCN mission is to provide telemetry, tracking and commanding (TT&C), communications, mission data dissemination and data processing support to DoD and other operational and Research, Development, Test and Evaluation (RDT&E) space systems. To fulfill this mission, the AFSCN consists of a large, complex network of nodes, including two main mission command and control centers and a world-wide network of ground stations with antennas to provide the telemetry, tracking and command (TT&C) interface to the space vehicles. These network assets are configured to receive telemetry and mission data from and send commands to satellites, as designated by a daily schedule.

Within the AFSCN, M&S technology is employed in training, on-orbit support, and planning/forecasting functions. Numerous existing or planned models, each focused on specific components, segments or functions, have been catalogued, but nowhere in the inventory is there a network level model. A network level model is one that provides "end-to-end" simulation of network behavior.

The Systems Modeling & Simulation Organization at Loral Space & Range Systems (LS&RS) has developed a concept for a network level model, based on an IHVRM approach. The NEtwork MOdel (NEMO) concept employs multiple levels of model fidelity, and mechanisms for determining when and how to focus on a particular level [Fall].

The benefits of such an approach are:

- The user has a framework for not only focusing on the area of interest, but also determining the impact of his decisions on the entire system.
- A high level (abstract) model requires less computer resources; therefore, results are obtained more rapidly.
- Existing models, already developed to yield particular results, are not duplicated or thrown away, but instead are integrated within NEMO so they can be used when applicable.
- Mechanisms built into NEMO automatically determine when the high level boundary conditions do not constrain the model sufficiently to produce usable results or the results indicate that there could be some conditions that could create undesirable outcomes; the user can select a more detailed model, vary the input stream, etc. to examine the problem in more detail.

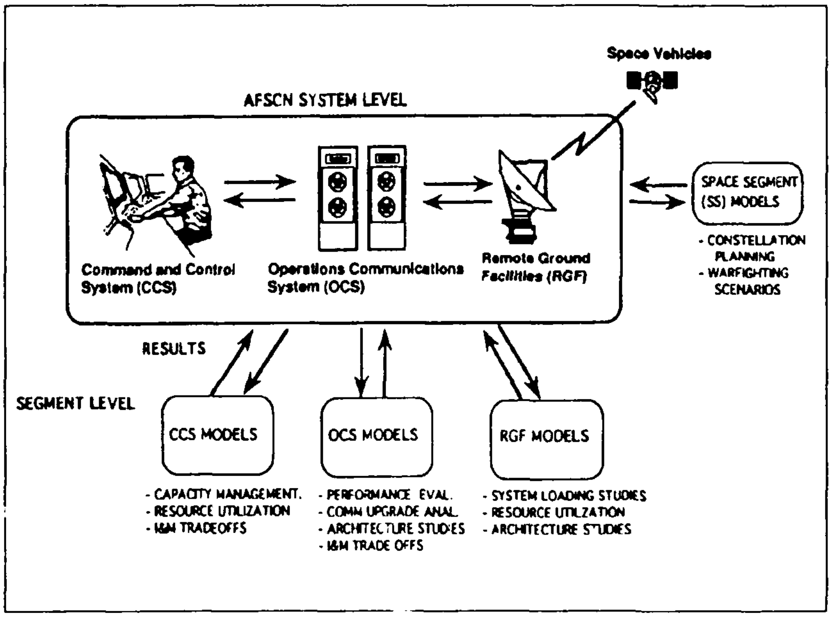


Figure 2: Conceptual System Level Model

NEMO

The AFSCN consists of three main segments: the Command and Control Segment (CCS), the Operations Communications Segment (OCS) and the Remote Ground Facility (RGF) Segment. At the system level, a model of the AFSCN would integrate high level models of the three main segments and their interface to a Space Segment (SS), which consists of the space vehicles they support. As shown in Figure 2, the system level NEMO provides an end-to-end modeling capability by incorporating results obtained from lower level models developed to support focused analyses. Figure 3 depicts the behaviors and characteristics of each segment that would be represented within NEMO.

The actual NEMO implementation would be a system of layered models, from high-level, low-fidelity to low-level, high fidelity models. As shown in Figure 4, each of the three AFSCN segments (CCS, OCS and RGF) would be represented by a hierarchy of models. The same behaviors would be represented at each level, but the level of detail, and therefore the level of fidelity, would increase from top to bottom levels.

For example, within the OCS there are time division multiplex/demultiplex (TDM) components that process multiple input/output data channels. Low-level, high fidelity models of the TDMs would contain the details of bit-level data processing, filling and unloading of data buffers,

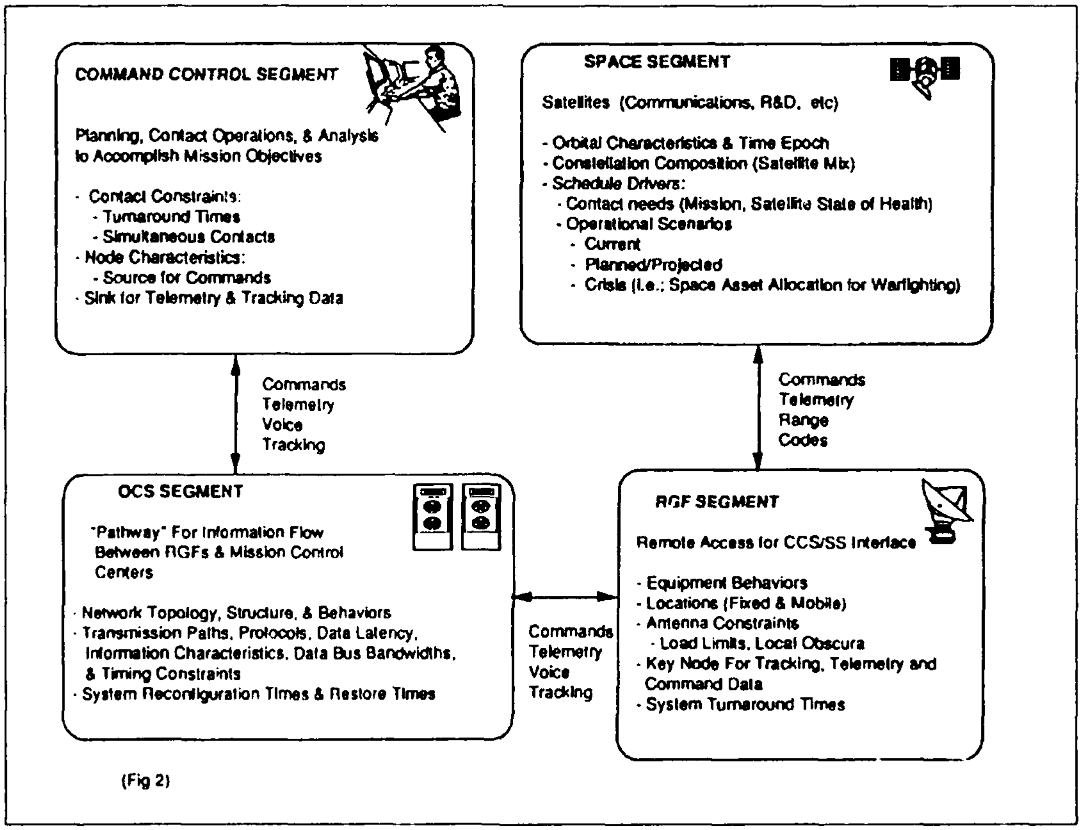


Figure 3: Modeled Behavior and Characteristics

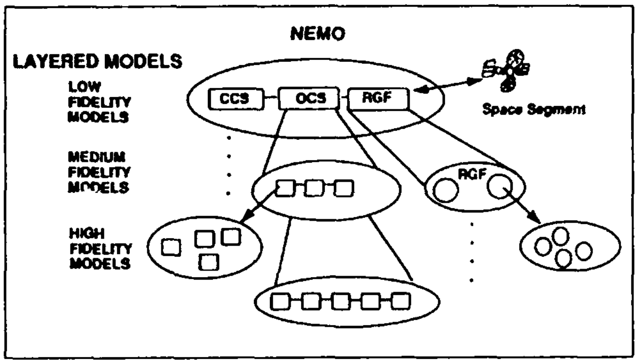


Figure 4: NEMO Consists of Hierarchical, Layered Models

channel contention logic and clock timing. In the high level, low fidelity NEMO, the TDMs would be represented as a fixed delay time of a signal through the network. The key, however, is that for a particular analysis, when the high level representation (a fixed time delay) is inadequate to give desired results, the low level model can be "zoomed in on" to yield more precise results.

Figure 5 depicts the types of analyses that NEMO can support. NEMO itself could become a component model in a synthetic-environment, warfighting scenario. In that event, NEMO will be required to conform to the protocols for communication between models being developed under the auspices of the DMSO, such as DIS (Distributed Interoperable Simulation) protocol and ALSP (Aggregate Level Simulation Protocol). The object-oriented implementation approach for NEMO will facilitate such interfaces.

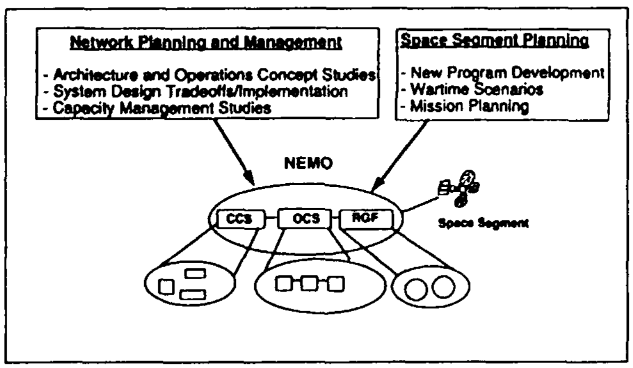


Figure 5: Framework of Analysis Supported by NEMO

LOAD GENERATOR

One primary area of focus for NEMO is the Load Generator or simulated schedule. Since the AFSCN operates according to a schedule prepared and deconflicted by a combination of humans and computers, any dynamic model of the AFSCN must incorporate a simulated schedule.

Employing the layered approach for modeling, NEMO will provide variable fidelity by accessing one of three tools for generating the loads for network analyses, as shown in Figure 6. At the most detailed, lowest level, a high-fidelity model, such as that provided with an existing AFSCN tool, the AFSCN Scheduling Program (ASP), could be used to generate a highly detailed schedule. To use ASP, the user must declaratively state each satellite, its orbit, and its contact requirements. ASP then simulates the preparation of the schedule which can be used to drive a simulation.

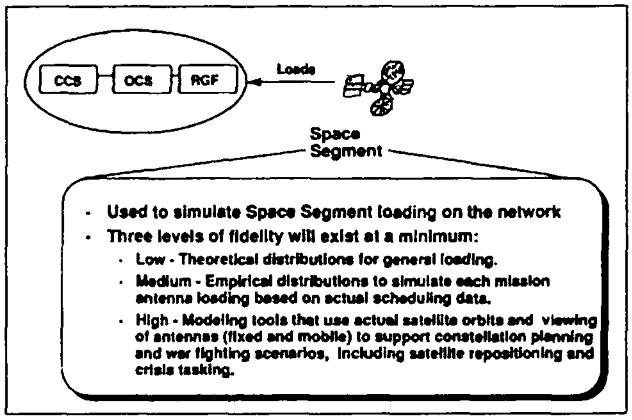


Figure 6: NEMO Includes Various Levels of Load Generation Capability

Although the high fidelity of ASP is necessary and desirable for some applications, it imposes constraints that make it unusable for other applications. See Figure 7, "Why the Number of Variables Must Be Controlled" for details.
Alternatively, a medium fidelity model, incorporating empirically derived, statistical distributions representing loading of specific antennas could be used, particularly if antenna loading fidelity is important. Examples of such models have been implemented by the LS&RS M&S Organization based on scheduling data from the current AFSCN scheduling system, the Automated Scheduling Tools for Range Operation (ASTRO).

WHY THE NUMBER OF VARIABLES NEEDS TO BE CONTROLLED

If each variable needed to be tested at 100 values for each possibility of the other variables, at one microsecond per test, we would get:

# of variables	# of tests	time to complete all tests	
1	100	0.1	millisecond
2	100^2	0.01	second
3	100^3	1.0	second
4	100^4	100.0	second
5	100^5	10,000	second = 2.78 hrs
6	100^6	1,000,000	second = 11.57 days
...			
9	100^9	10^12	second = 317 centuries

Figure 7: Why the Number of Variables Must be Controlled

At the highest level, a low fidelity model that represents a theoretical statistical distribution of general AFSCN loading would provide the general loading profile sufficient to perform many analyses, particularly when analysis time is short or specific loading is unimportant.

Within NEMO, we are developing a capability called AFSCN Capacity Engine (ACE), a high level, abstract model that emulates an AFSCN schedule and estimates antenna loading. The danger with abstraction is oversimplification which can result in incorrect conclusions (e.g., a total AFSCN antenna availability is spread evenly across antennas and indicates sufficient capacity, when in fact several antennas are oversubscribed and several are undersubscribed). Therefore, ACE has been designed to provide enough abstraction to provide flexibility and increased throughput but to retain sufficient fidelity to adequately capture the behavior of the essential components. This capability is accomplished through the incorporation of software mechanisms that propagate sensitivity throughout the simulation, providing insights into the precision of the model.

An overriding philosophy during the development of NEMO is that of baselining; that is, to the extent possible, we develop and validate models that represent the AFSCN as it is today, then use that baseline to generate predictors of behaviors for which no empirical data exists. This process is detailed in Figure 8, entitled "The Baselining Process." This baselining process ensures, to the extent possible, the integrity of conclusions drawn for "what if" types of analyses.

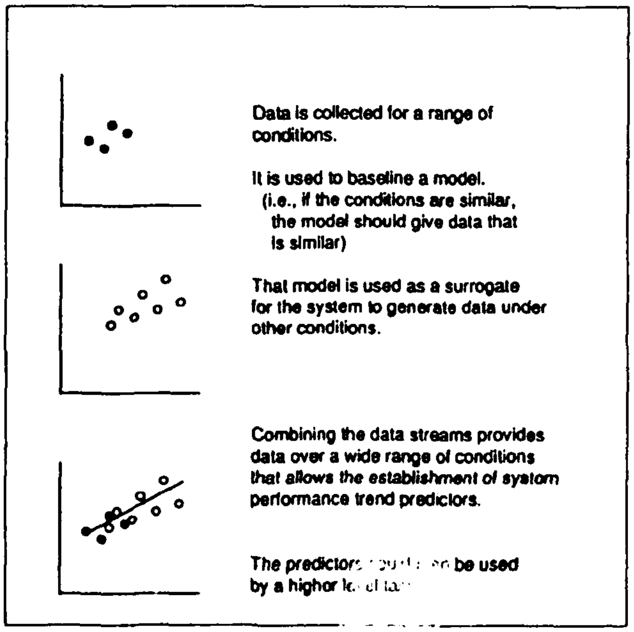


Figure 8: The Baselining Process

CONCLUSION

The DoD has mandated increased reliance on M&S for system acquisition. Technologies, in particular object-oriented technology, are coming on line that will allow more flexible models to be developed that can address a wide range of decision support questions.

The AFSCN has numerous models that are currently focused on particular applications, segments, or components. These models could be incorporated into the NEMO concept presented in this paper to provide a more robust AFSCN analysis capability. In addition, NEMO could provide the gateway to inclusion of AFSCN models in the Synthetic Environments being looked to for warfighter training and system acquisition.

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Dr. Thomas C. Fall is the Principal Engineer in the LS&RS Systems Modeling and Simulation Organization. Dr. Fall has over 12 years experience in modeling and simulation in a wide variety of DoD application areas. He has been technical lead on projects using modeling to do data fusion from multiple sources to provide information to decision makers in arenas spanning tactical to strategic to national.

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Marilyn Golden manages the LS&RS Systems Modeling and Simulation Organization. Ms. Golden has led advanced technology programs for the past ten years aimed at the development and integration of state-of-the-art technology, namely expert systems, model-based reasoning, modeling and simulation, neural networks, and 2D and 3D graphics, to enhance space and range capabilities.

University Technical Interaction Program (UTIP)

Charlie Jarrel, C&DP/Paramax
Bob Powell, C&DP/Paramax

The University Technical Interaction Program (UTIP) was conceived to establish a professional and technical liaison between universities and CWIA representatives to foster a think-tank perspective for generating ideas that support the objectives of CWIA's Advanced Technology Program.

The UTIP concept involves using graduate students (and undergraduates in certain instances) to conceptualize new-age satellite command and control systems, and explore new technologies for enhancing the AFSCN state of the art. Concept establishment involves investigating today's technologies (and tomorrow's forerunners) as foundations for future system development. UTIP provides three distinct benefits:

1. Students participate in a proactive environment. They receive college credit towards specific degree programs for their thesis papers; these papers are evaluated by Air Force representatives, giving students the experience of real-world impact.

2. The CWIA community receives fresh viewpoints. In most cases, students have relatively little experience with current AFSCN operational requirements; this lessens the possibility of introducing biases and other obstacles that would reduce creative vision.

3. The UTIP process further establishes useful networks for technology research and development. By approaching university engineering and computer science deans, an information exchange is established with professionals who share current university/private R&D efforts that may bolster KTA objectives.

The UTIP is evolutionary. Guidelines are established with each participating student to ensure that the direction of thought is adequate for AFSCN needs. For example, a graduate-level student from a local university (Colorado Technical College) is interested in preparing a thesis paper on ideas for future 50th Space Wing command post operations. The student is a USAF Captain currently working at Falcon Air Force Base.

Future plans call for contacts to be made with the USAF Adacemy Engineering Department to discuss similar student involvement at that institution. The CWIA Project Officer is Captain Chris Weakley.

Joint Satellite Control Human-Computer Interface Working Group Effort

Kathleen Rothar Watson, Loral Space & Range Systems

The Human-Computer Interface (HCI) Key Technology Area (KTA) has been actively involved in the Joint Satellite Control HCI Working Group (HCIWG) effort, which is tasked with developing an HCI guideline/ standard tailored specifically to the satellite control environment. The focus of this effort is on operator involvement throughout the standards-making process, ensuring the unique needs of the satellite control community are met. In the process, the KTA and the HCIWG have mutually benefitted. The HCIWG received information and focus from the KTA, and the KTA received the results of an extensive task analysis. The HCIWG task analysis identified tasks in detail and confirmed them with the user community, and it will be used by the KTA as the basis for forecasting and developing roadmaps for infusion of HCI technologies into the AFSCN.

THE HCIWG

The Human-Computer Interface (HCI) Key Technology Area (KTA) actively participates in the Joint Satellite Control Human Computer Interface Working Group (HCIWG), an ongoing collaborative effort led by AFSPACECOM and AFMC/SMC to improve the interoperability, standardizat on, efficiency, and quality of human computer interfaces for all Department of Defense (DoD) satellite control systems. This group is composed of personnel from the Air Force, Navy and Army satellite control user communities, since well as individuals from government agencies (e.g., Aerospace) and contractors (e.g., IBM, Loral, Paramax, Lockheed).

The main goal of the HCIWG is to produce an HCI guideline/standard tailored specifically for use in AFSCN system development and enhancement. In preparation for this endeavor, the HCIWG reviewed current and proposed HCI standards considered applicable to the satellite control environment. Through this review process, the group observed that HCI guidelines/ standards, in general, cover design guidance for older HCI technologies. These older HCI technologies primarily include text based, command line and form-fill entry HCIs. This poses a problem since most future acquisitions undoubtedly will involve newer technologies, for which guidance has not yet been well researched or established.

Since the value of this new HCIWG guideline/standard involves current and future acquisitions, it is critical that the HCI KTA provide to the guidelines/standards activity its primary resource: the accumulating knowledge base and expertise on emerging HCI technology information provided by the Advanced Technology Program. Therefore, the main role the KTA plays in the HCIWG is to anticipate the direction of emerging technologies, identify the applicability to future AFSCN interests and incorporate those new ideas into AFSCN guidelines/standards development activities.

It is clear from the HCIWG guidelines/standards review that sources addressing newer HCI technology need to be identified and publicized. Therefore, the KTA has undertaken an initial review of a few recently published guidelines and standards. Sources currently being reviewed by the KTA for the HCIWG include publications from the commercial world providing guidance for graphic design (Marcus, 1992), Macintosh-style Graphic User Interfaces, or GUIs (Tognazzini, 1992; Apple Computer, 1992), general HCI design guidance for practitioners (Schneiderman, 1992), and on-line documentation and hypertext interfaces (Horton, 1990). In addition, the KTA and HCIWG are in the process of formally reviewing the DoD HCI Style Guide (Sept 30, 1992), which is proving to be a rich compendium of the most current applied research and standards that address newer HCI technologies (e.g., large screen displays, decision support aids).

HCIWG USABLE PRODUCTS TO DATE

At this point in time, the HCIWG has already generated usable products that will fill major gaps developers have experienced on past contracts using conventional contract requirements documentation (e.g., A-specs, MIL-STD-1472). These include the functional descriptions of the satellite operations environment from the operator's perspective (i.e., task analysis, the operational scenarios), required generic HCI capability, evaluations of the most recently developed prototypes (e.g., ASW II, SAGE, IPAS), and the review of existing and draft version HCI standards in the community (e.g., AIAA Recommended Practice for Human-Computer Interfaces for Space Systems Operations).

The HCIWG is working hard to produce a useful standard quickly enough to meet the needs of the changing AFSCN. The necessary steps to produce a useful standard beyond what is already available (e.g., MIL-STD-1472) is time consuming. But in spite of this challenging schedule, the HCIWG expects to release its first working draft June 1993. This document will be disseminated to the broadest possible audience, notably the user communities.

The HCIWG effort has provided usable products that mutually support the KTA effort, as well as for its own purposes. Most useful of these is a detailed task analysis of critical satellite control operations and operational scenarios that are relatively independent of specific HCI technologies. The task analysis is being used for identifying candidate functional areas that could benefit from a particular technology infusion. The HCIWG produced the task analysis as a basis for identifying required HCI capability that could be applied across mission functions. The HCIWG also performed an extensive review of existing HCI standards (i.e., draft and published). These standards are listed in Table 1.

FUTURE OF THE HCIWG GUIDELINE/STANDARD

Based on the HCIWG effort, the KTA observes and promotes the development of new technology and standards from two perspectives: 1) the content coverage of new technologies in the standard, and 2) improved methods of access to the standard itself. From the first perspective, the final HCIWG guideline/standard will need to cover newer HCI technologies that are likely to be used in new system acquisitions (e.g., GUIs). From the second, the HCIWG came to realize that even when HCI standards and guidelines serve the needs of both operators and developers, they are useless if developers cannot easily access and use them during the design process. Therefore, standards and guidelines must be made more accessible and usable to the developer community. If funding permits, the HCIWG hopes to develop the final guideline/standard on a hypermedia system. This approach handles the guidelines/standards electronically with appropriate cross linking of documents, HCI examples and rule exceptions. It is envisioned for the future, a computer assisted HCI design component could be incorporated into the software development tool of the developer (or generic user), that would automatically make and implement many of these decisions. For example, much of color science and graphic design knowledge may some day soon be embedded in computer-based expert systems which could automatically apply the knowledge appropriately as the user needed (Marcus, 1992).

The KTA plans to continue to participate in the HCIWG effort and funnel any useful technology information that can be used in the standards activity. For example, the KTA is currently involved in publishing a series of papers, one planned for multimedia and the other groupware, that will specifically address potential aspects of these technology areas amenable to standardization or guidance. In this way, the KTA also can provide more focus for the HCIWG on new technology areas of concentration.

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Kathleen Rothar Watson is the technical lead on the Loral HCI KTA effort since February 1992. She has 12 years experience in human-computer interaction design and development, gained from her employment at NASA-Ames Research Center, Monterey Naval Postgraduate School and Loral Space and Range Systems.

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CWIA Trusted Systems Workshop

Part 1: Summary of Day 1

Edited by Dr. D. Bodsford (Bods) Smith, Jr.,
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The Technology and Architecture Division of the Space and Missiles Systems Center (SMC/CWIA) conducted a Trusted Systems Workshop in September of 1992 as part of the CWIA Advanced Technology Program. In this workshop, nationally known Trusted Systems and Systems Safety experts from DoD, industry, academia, and government laboratories came together to discuss the state-of-the-art in Trusted Systems and Systems Safety, to learn more about the AFSCN, and to investigate and recommend how these technologies may be applied in the Network. The following article is the first half of a two-part summary of the objectives, presentations, and benefits derived from the Workshop. The second part will be presented in a subsequent technical report.

The Technology and Architecture Division of the Space and Missiles Systems Center (SMC/CWIA) conducted a Trusted Systems Workshop in September 1992 as part of the CWIA Advanced Technology Program. In this Workshop, nationally known Trusted Systems and Systems Safety experts from DoD, industry, academia, and government laboratories came together to:

- Discuss the current state-of-the-art in Trusted Systems and Systems Safety
- Forecast the future maturation of Trusted Systems and Systems Safety technologies
- Focus the high-level technical horsepower from the Trusted Systems and Systems Safety communities on a variety of Air Force Satellite Control Network (AFSCN) issues
- Provide an environment in which AFSCN personnel could benefit directly from the participants' expertise. This environment provided both formal and informal settings for interaction between AFSCN personnel and the Workshop participants.

The Workshop was conceived of, arranged, and hosted by Loral. It was organized into four half day sessions, each session being devoted to one of the following topics: security functionality, present and future security architectures, high assurance technologies, and safety architectures. Invited experts presented papers at each session.

This paper is a two-part adaptation of a more extensive report[1], to which the reader is referred for a more complete and in-depth coverage of the Workshop. Part 1 covers the Day 1 activities, while Part 2 summarizes Day 2 activities. Part 2 will be presented in the second issue of this Journal. The overall article presents:

- An overview of the Workshop and its objectives and payoffs, which include ten conclusions of importance to the AFSCN and some additional "bonus" benefits
- A synopsis of each presentation
- Ten significant conclusions of importance to theAFSCN
- A summary of payoffs resulting from the Workshop.

In addition to these, the larger report contains a brief tutorial on technical issues related to Trusted Systems and Systems Safety, commentary related to each presentation and to Trusted Systems and Systems Safety issues in general, a list of attendees, complete texts of the contributors' papers, and hard copies of viewgraphs for most of the Workshop presentations. Requests for copies of the full report should be made to SMC/CWIA.

BACKGROUND

The Trusted Systems Workshop was an outgrowth of the SMC/CWIA Advanced Technology Program AFSCN Key Technology Area (KTA) effort. One of the AFSCN Key Technologies researched in GFY 1992 was "Trusted Systems," and the Workshop was envisioned by Loral as a highly effective and efficient means of achieving the KTA objectives, which were to identify:

- Current Trusted Systems Technology that can be used to provide multilevel security features and enhance software safety for the AFSCN
- Means of integrating near term computer and communication security products into the current AFSCN architecture
- Projected future security and safety technologies that could be integrated into the AFSCN architecture and operations
- Processes by which these technologies may be integrated into the future AFSCN.

In addition, the Workshop was seen as a means of increasing the awareness of the AFSCN community regarding resources available in the areas of Trusted Systems and Systems Safety.

Newport Beach, CA was selected as the site for the Workshop, which was held on September 17-18, 1992. Loral invited nationally known experts in the areas of Trusted Systems and Systems Safety from DoD, industry, academia and government laboratories to assess the current state-of-the-art and to forecast future developments in their areas of expertise. SMC/CWIA invited personnel from the AFSCN community with in-depth knowledge about many aspects of the AFSCN, including its mission, architecture, concept of operations, user communities, security posture, and future requirements.

Dr. George Dinolt of Loral hosted the workshop and organized it into four sessions dealing with security functionality, system architecture and requirements, assurance, and safety. Thirteen invited experts gave formal presentations in these sessions. A notable participant from the AFSCN, Lt Col Bill Price (Air Force Space Command/ LKXS), contributed an excellent paper entitled "Accreditation Strategy for the Air Force Satellite Control Network."

The Workshop format was designed to allow sufficient time for AFSCN overview and stage setting presentations, as well as question and answer sessions. In many cases, the question-and-answer portions led to wide-ranging, spontaneous, and lively discussions among all the participants. As indicated earlier, these discussions are captured in the referenced report.

AGENDA

Day 1 (September 17, 1992)
- Day 1 Introductory Remarks and Stage Setting
- Session I: Security Functionality
- Session II: System Architecture and Requirements

Day 2 (September 18, 1992)
- Day 2 Introductory Remarks
- Session IV: Safety

THURSDAY INTRODUCTORY REMARKS AND STAGE SETTING

The Workshop was opened with introductory remarks by Maj Davidovich and Dr. Dinolt. Lt Col Price also handed out a copy of his paper, which provides a description of AFSCN components, functions, history, network security environment, and lessons learned, and could provide useful background information for those Workshop participants unfamiliar with the AFSCN.

Maj Stevan M. Davidovich, Chief, SMC/CWIA: "Welcoming Remarks"

Maj Davidovich began the Workshop by thanking all participants for attending. He gave a brief introduction on the goals and objectives of the KTA initiative. He noted that for the next eighteen months, a window of opportunity exists for the AFSCN to coordinate with the Space Segment on operations concepts. This coordination can set the stage for technology insertion for the rest of the decade. Another such window of opportunity may not exist until well past the year 2000.

Maj Davidovich also noted that the AFSCN Executive Council has approved a list of eleven projects to be developed over the next twenty five years. One item on the list is Multilevel Security (MLS). This is the first time security has had this level of visibility. As a result, the security community now has the opportunity to define the role and approach for security on many forthcoming projects. Maj Davidovich emphasized that an important goal of the AFSCN Executive Council is to transition trusted system technology from a research and development environment to Government applications.

Dr. George Dinolt, Loral: "Introductory Remarks and Stage Setting"

Following Maj Davidovich's talk, Dr. George Dinolt, technical host of the meeting, welcomed the participants and observers. He presented a brief overview of the goals of the Workshop and provided a framework for the discussions.

SESSION I: SECURITY FUNCTIONALITY

Examples of Security Functionalities are:

- Traditional" MLS systems
- New technologies (e.g., Compartmented Mode Workstations) and beyond
- MLS networking products
- Security related protocols.

Mr. Bill Neugent, MITRE Corporation: "Predictions for INFOSEC Advances"

Mr. Neugent noted that lower assurance platforms, particularly B1, have become more extensive in the past five years. [For an explanation of these and related terms, the reader is referred to the "rainbow Series" of books published by the National Computer Security Center. Of particular importance to the discussion here are the "Red" and the "Orange" books.] Some appear very promising. It is vital from the vendors' standpoint to penetrate markets beyond a tiny subset of DoD systems, to be able to provide ongoing improvements in these lower assurance platforms.

Future environments will include extensive use of digital signatures, biometrics, and other more secure and sophisticated protection mechanisms. Digital signatures, in particular, will play a significant role in network architectures of the future. Increased protection is required because the problem of system "crackers" has grown from a nuisance to a menace. Increased reliance on computer systems can have catastrophic results when the systems are misused or disabled.

Too much emphasis is placed on creating general purpose, high assurance systems. There is a need to create security solutions tailored to the applications. For example, the use of trusted workstations combined with a filtering router provides multiple, independent checks as an alternative to relying on just one check. As another example, an A1 system is still susceptible to security administrator errors. Relatively primitive administrator interfaces on high-assurance systems might make them more susceptible to error than lower-assurance systems that provide a rich suite of administrator aids. Both of these examples differ from the approach in the Orange Book.

Ms. Ruth Nelson, GTE:
"Trusted Systems and Current Computing"

Ms. Nelson believes that the trust technology in use today is based on outmoded architecture. Specifically, it is geared to the technology of the 1970's, where there were multiple users of a single system. Today, with the advent of extremely powerful desktop computers and workstations, the paradigm is a single user connected to a network, with the network potentially having global interconnectivity, and with significant computing power available locally. Such systems are heterogeneous, dynamic, and highly distributed. As a result, the Orange Book and other Rainbow documents are inapplicable to them.

One must assume a modern (networked) system configuration is always changing. It is no longer possible to determine the configuration of a network that has world wide connectivity. The addition and/or deletion of connectivity to other computers or networks is beyond the control of a local user or administrator.

As a result of these changes from the Orange Book model, Ms. Nelson offered the following recommendations:

- Concentrate on robustness, not configuration control.
- Recognize that local control of communications and processing is key; global control is impossible.
- Do not attempt generic security solutions, but rather tailor the requirements and mechanisms to a specific mission.

Dr. Dixie Baker, Aerospace Corporation:
"From Whence Cometh Trustworthiness?"

There is a major inadequacy in the Orange Book, in that it forces specific combinations of functionality and assurance, rather than letting these be independent properties of a given system. For example, a B1 platform contains a required amount of functionality, and a required amount of assurance. A particular project might need less functionality and more assurance, or vice versa. There is no way that the Orange Book can accommodate this flexibility.

As a result, there is a new government project underway, jointly sponsored by National Security Agency (NSA) and National Institute of Standards and Technology (NIST), formerly known as the National Bureau of Standards. The project is defining a new United States Information Technology Security Standard (ITSS) to be applied throughout the federal government. Dr. Baker is playing a lead role in the development of this standard.

The standard is based on the notion of Protection Profiles that unite functionality, assurance, and dependency considerations to describe generic protection needs. Such generic needs could include confidentiality, integrity, service assurance, and software safety. These generic needs would need to be tailored and instantiated on a project-specific basis. A Protection Profile is composed of four parts: rationale, functionality, assurance, and dependencies. Dr. Baker elaborated upon these parts, and explained their benefits and potential impacts throughout various phases of the life cycle, including system acquisition.

Dr. Baker also made a point that there is confusion between the notions of "trust" and "trustworthy," that ITSS is attempting to clarify. In a slide entitled "Key Definitions," Dr. Baker presented definitions of: trusted computer system technologies, trusted computer system engineering, assurance, trusted system, and trustworthiness.

Dr. Baker also presented a sequence of slides describing thirteen "technology enhancements" and the time frame in which they are expected to become viable. Examples of technology enhancements include compartmented mode workstations, multilevel database management systems, and formal design verification. The time frames were broken out into three phases: 0—2 years, 3—7 years, and 8—25 years.

SESSION II: SYSTEM ARCHITECTURE AND REQUIREMENTS

A basic question is, "How do changes in technology affect system architectures?" Some examples of technological changes that affect system architecture are:

- Movement to standalone versus networked systems
- Changes in scale, size, complexity, and number of system components
- Changes in performance
- Changes in price
- Development of dynamic systems.

A second basic question is, "How do changes in technology affect system requirements?" Some examples of such changes that affect system requirements are:

- Open systems and standardization
- Increased interconnectivity
- Increased interdependence
- Heterogeneity.

Mr. John Nagle, Stanford University: "The Threat in the Post-Cold War World"

Mr. Nagle began his talk by noting that although he had been invited to the Workshop to discuss computer security impacts on the AFSCN, the changing threat environment motivated him instead to concentrate on threats. In looking to the future, Mr. Nagle pointed out that the main threat has changed with the decline of monolithic Communism. There is no longer an "Evil Empire," leading some politicians and citizens to assume that the costs associated with defense and security are exorbitant and unjustified. Mr. Nagle explained why he believes such assumptions are incorrect and dangerous.

He pointed out that in the wake of Desert Storm there is ample evidence that high technology systems do work, and this will cause these systems to be focused objects of attack in future conflicts. Mr. Nagle explained the likely forms such attacks could take, including the use of "crackers" funded by hostile intelligence services to temporarily disable Tracking, Telemetry, and Commanding (TT&C) software, and physical attacks on AFSCN ground stations throughout the world.

Mr. Nagle concluded by presenting a brief sketch of techniques that could protect against these newer types of threats. These techniques protect against single point of failure and include timeouts, confirmations, authentications, and the use of built-in suspicions for newly developed satellites.

Mr. Clark Weissman, Paramax: "On a Migration Strategy for the AFSCN to a MLS Client Server Environment (MLS-CSE)"

Mr. Weissman's key theme is that securable architectures need to be developed that are independent of the implementation approach used for a given project. A basis for this can be found in an Open Systems approach, in particular, with the client-server model.

Current security approaches are usually too custom-made, requiring a redefinition of security properties for each system. In addition to prohibitive cost, the system is often outmoded before it is used. Using COTS as an alternative, however, also poses problems: most COTS products are not rated at a high enough level of assurance for effective system use; they often do not address the correct threats; and they combine parts resulting in a mixture that may be difficult to accredit (or even fully understand). An example is the combination of a secure operating system with a secure data base management system. The problems inherent in combining the two are the ongoing subject of a number of research papers.

He proposed a client-server model in an Open Systems Environment (OSE) that does not concentrate upon current technology, but rather addresses the design of systems that could securely integrate emerging COTS products as they become available.

Mr. Paul Cook, Falcon Communication Corporation: "Integrating the Components"

Mr. Cook observed that the current state of security engineering is similar to the state of communications engineering that existed in the early DoD data communications network development time-frame. Back then each instance was unique and custom-made. There are examples of Army, Navy and Air Force procurements that provide implementations of the same data communications functionality. Each performs the same functions, yet each was built from scratch, essentially independent of the others, with little transfer of technology.

Although COMPUSEC (Computer Security) systems are harder to define and implement than COMSEC (Communications Security), COMPUSEC is often cheaper, more flexible, and more powerful than COMSEC. In many current systems COMPUSEC controls COMSEC. This results in security anomalies, because COMSEC is guided by many years of experience and rules of thumb, which are generally lacking in COMPUSEC. For example, in the COMSEC environment, there are a set of invariants widely known within the community, such as the restriction against RED and BLACK data on the same bus.

Mr. Cook also pointed out that even after a complex system is accredited, there is a problem in maintaining that accreditation. The complexity of many modern communication systems and networks makes it difficult and costly to re-accredit the system when substantive changes occur.

For the future, Mr. Cook suggested that it would be wise to investigate the development of a security engineering methodology that would support threat assessment and failure mode analysis in addition to the more typically covered topic of correct operation of systems and software. Threats are one of the prime drivers in the decision process for a design approach.

Prof. John McHugh, University of North Carolina at Chapel Hill: "We Have Met the Enemy and He is Us (Securing Tomorrow's Systems)"

Dr. McHugh explained his intriguing title by noting that the human element is often the most vulnerable, regardless of how secure the remaining components of a system may be. He illustrated this in a variety of areas, including covert channels, a shared memory bus multiprocessor, and a system with a voluminous audit trail that overwhelms all human capacity for comprehension. Another aspect of human weakness occurs when designers deliberately misstate security constraints, or select the wrong level of granularity. In his opinion, this problem will only be exacerbated in the future by more complex systems.

His most dramatic example was visual, and dealt with the inability of humans to detect that a digitized picture had been corrupted. He presented two images: a Landsat image of Raleigh-Durham Airport (RDU), and a Landsat image of RDU contaminated with an F-16 aircraft. The contamination was achieved by allocating the lowest three bits per pixel to the aircraft. There was no discernible difference in the two images to the Workshop audience. He then displayed the F-16 image that was extracted from the corrupted image, and compared it to a "normal" image of an F-16. Again, there was little if any difference noted by the audience. Dr. McHugh then presented a similar example in which a hidden image of RDU was present in a picture of textual data. These examples are convincing evidence that imagery can be used as a very high bandwidth covert channel, with little ability of humans even to detect that a covert channel is operating at all.

This concludes Part 1 of this article. Part 2 will provide a summary of the Day 2 activities, a conclusion, and a list of benefits derived from the Workshop.

REFERENCE

1. "Trusted Systems Key Technology Area End-of-Year Report," 30 September 1992. Prepared by Loral Space and Range Systems for SMC/CWIA.

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